HIGH SCHOOL BOTANY

BERGEN

FRONTISPIECE. — A Shade Plant, Jack-in-the-Pulpit

HIGH SCHOOL BOTANY

BY

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PREFACE

This book is written upon the same plan as the author's *Elements of Botany*. A few chapters stand here but little altered from the former work, but most of them have been rewritten and considerably enlarged, and many new ones have been added. The principal changes in the book as a whole are these:

1. Most of the discussion of ecological topics is put by itself, in Part II.

2. The amount of laboratory work on the anatomy and physiology of seed-plants is considerably increased and additional experiments are introduced.

3. The treatment of spore-plants is greatly extended, so as to include laboratory work on the most important groups.

4. The meagre Flora which accompanied the earlier book has been replaced by one which contains fairly full descriptions of nearly seven hundred species of plants. Most of these are wild, but a considerable number of cultivated species have been included, mainly for the convenience of schools in large cities.

Ample material is offered for a year's course, four or five periods per week. The author is well aware that most schools devote but half a year to botany, but the tendency sets strongly toward allowing more time for this subject. Even in schools where the minimum time allowance is devoted to botany, there is a distinct advantage in being provided with a book which allows the teacher considerable option as regards the kind and amount of work which he shall offer to his classes.

Suggestions are made in the teacher's *Handbook*, which accompanies this volume, in regard to shaping half-year courses.

The latest authorities in the various departments of botany have been consulted on all doubtful points, and the attempt has been to make the book scientifically accurate throughout, yet not unduly difficult.

Most of the illustrations have been redrawn from those in standard German works of an advanced character, or drawn from nature or from photographs, expressly for this book. Besides the sources of drawings acknowledged in the author's *Elements*, many cuts have been taken from the botanies of Frank, Prantl, Detmer, Murray, and Bennett and Murray, as well as from Schimper's *Pflanzengeographie*.

Of the drawings from nature or from photographs, some figures, and Plates I, VII, and VIII, are by Mr. Edmund Garrett of Boston; several figures, the Frontispiece, and Plates II, IV, X, XI, are by Mr. Bruce Horsfall of New York; several figures are by Mr. F. Schuyler Mathews of Boston; a large number of figures and Plate V are by Mr. E. N. Fischer of Boston; several figures are by Mr. E. R. Kingsbury of Boston and Dr. J. W. Folsom of the University of Illinois.

Thanks for the use of photographs are due to Mr. H. G. Peabody of Boston (Fig. 234), to Mr. J. H. White of Boston (Figs. 32, 75, 222), to Professor Conway MacMillan of the University of Minnesota (Frontispiece), and to Professor F. V. Coville of Washington (Plate VII). Figs. 28 and 275 are taken by permission from the *Primer of Forestry*, issued by the Division of Forestry, U. S. Department of Agriculture. Figs. 263, 264, 276 are copied by permission from Professor W. J. Beal's *Seed Dispersal*, and Figs. 226, 229, 233 from Professor W. M. Davis's *Physical Geography*. Fig. 269 is from a photograph by Professor C. F. Millspaugh of Chicago. Plate IV is from a photograph by Dr. H. J. Webber.

Most of the redrawn illustrations (not microscopical) from various European sources are by Mr. Fischer. Most of the microscopical ones (and a number of figures from nature) are by Dr. J. W. Folsom of the University of Illinois, and many of both classes are by Mr. Mathews. Thanks are due to Professor J. M. Holzinger of the Winona (Minn.) State Normal School, to Professor L. Murbach of the Detroit High School, and to Mr. I. S. Cutter of Lincoln, Nebraska, for their many discriminating criticisms of the proof of Parts I and II. Mr. Samuel F. Tower of the Boston English High School, Professor Charles V. Piper of the Washington State Agricultural College, and Dr. Rodney H. True, Lecturer on Botany at Harvard University, have all read the whole or large portions of Part I and given valuable suggestions. Professor W. F. Ganong, of Smith College, has read and criticised Part II.

The chapters on spore-plants, excepting a small amount of matter retained from the *Elements of Botany*, are entirely the work of Mr. A. B. Seymour of the Cryptogamic Herbarium of Harvard University.

The author has attempted to steer a middle course between the advocates of the out-of-door school and of the histological school of botany teaching. He has endeavored never to use a technical term where he could dispense with it, and on the other hand, not to become inexact by shunning necessary terms. In deciding questions of this sort, *a priori* reasoning is of little value; one must ascertain by repeated trials how much of a technical vocabulary the average beginner in botany can profitably master. The teacher who has discovered that not one of the boys in a division of thirty-six pupils knows that his own desk-top is of cherry wood may well hesitate about beginning his botany teaching with a discourse on centrospheres and karyokinesis. It has been assumed throughout this book that, other things being equal, the knowledge is of

most worth which touches the pupil's daily life at the most points, and therefore best enables him to understand his own environment. On the other hand, the author has no sympathy with those who decry the use of apparatus in botany teaching in secondary schools and who would confine the work of their pupils mainly within the limits of what can be seen with the unaided eye. If the compound microscope plainly reveals things shown only imperfectly by a magnifier and not seen at all with the naked eye, — use the microscope! If iodine solution or other easily prepared reagents make evident the existence of structures or substances not to be detected without them, — then use the reagents! No one thinks of denying a boy the use of a spyglass or a compass for his tramps afield or his outings in a boat because he has not studied physics. No one would refuse to let an intelligent boy or girl use a camera because the would-be photographer had not mastered the chemical reactions that follow upon the exposure of a sensitized plate. Yet it is equally illogical to defer some of the most fascinating portions of botanical study until the college course, to which most never attain. When the university professor tells the teacher that he ought not to employ the ordinary appliances of elementary biological investigation in the school laboratory because the pupils cannot intelligently use them, the teacher is forced to reply that the professor himself cannot intelligently discuss a subject of which he has no personal knowledge. The pupils are deeply interested; they prove by their drawings and their recitations that they have seen a good way into plant structures and plant functions; then why not let them study botany in earnest?

J. Y. B.

CAMBRIDGE, January, 1901.

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INTRODUCTION

"Botany is the science which endeavors to answer every reasonable question about plants."[1]

The plant is a living being, provided generally with many parts, called *organs*, which it uses for taking in nourishment, for breathing, for protection against its enemies, and for reproducing itself and so keeping up the numbers of its own kind. The study of the individual plant therefore embraces a variety of topics, and the examination of its relation to others introduces many more subjects.

Morphology, or the science of form, structure, and so on, deals with the plant without much regard to its character as a living thing. Under this head are studied the forms of plants and the various shapes or disguises which the same sort of organ may take in different kinds of plants, their gross structure, their microscopical structure, their classification, and the successive stages in the development of the individual plant.

Plant Physiology treats of the plant in action, how it lives, breathes, feeds, grows, and produces others like itself.

Geographical Distribution, or botanical geography, discusses the range of the various kinds of plants over the

[1] Professor George L. Goodale.

earth's surface. Another subdivision of botany, usually studied along with geology, describes the history of plant life on the earth from the appearance of the first plants until the present time.

Systematic Botany, or the classification of plants, should naturally follow the examination of the groups of seed-plants and spore-plants..

Plant Ecology treats of the relations of the plant to the conditions under which it lives. Under this division of the science are studied the effects of soil, climate, and friendly or hostile animals and plants on the external form, the internal structure, and the habits of plants. This is in many respects the most interesting department of botany, but it has to be studied for the most part out of doors.

Many of the topics suggested in the above outline cannot well be studied in the high school. There is not usually time to take up more than the merest outline of botanical geography, or to do much more than mention the important subject of *Economic Botany* — the study of the uses of plants to man. It ought, however, to be possible for the student to learn in his high-school course a good deal about the simpler facts of morphology and of vegetable physiology. One does not become a botanist — not even much of an amateur in the subject — by reading books about botany. It is necessary to study plants themselves, to take them to pieces and make out the connection of their parts, to examine with the microscope small portions of the exterior surface and thin slices of all the variously built materials or *tissues* of which the plant consists. All this can be done with living specimens or with those taken

from dead parts of plants that have been preserved in any suitable way, as by drying or by placing in alcohol or other fluids which prevent decay. Living plants must be studied in order to ascertain what kinds of food they take, what kinds of waste substances they excrete, how and where their growth takes place and what circumstances favor it, how they move, and indeed to get as complete an idea as possible of what has been called the behavior of plants.

Since the most familiar and most interesting plants spring from seeds, the beginner in botany can hardly do better than to examine at the outset the structure of a few familiar seeds, then sprout them and watch the growth of the seedlings which spring from them. Afterwards he may study in a few typical examples the organs, structure, and functions of seed-plants, trace their life history, and so, step by step, follow the process by which a new crop of seeds at last results from the growth and development of such a seed as that with which he began.

After he has come to know in a general way about the structure and functions of seed-plants, the student may become acquainted with some typical cryptogams or spore-plants. There are so many groups of these that only a few representative ones can be chosen for study.

Part I

STRUCTURE, FUNCTIONS, AND CLASSIFICATION OF PLANTS

CHAPTER I

THE SEED AND ITS GERMINATION

1. Germination of the Squash Seed. — Soak some squash seeds in tepid water for twelve hours or more. Plant these about an inch deep in damp sand or pine sawdust or peat-moss in a wooden box which has had holes enough bored through the bottom so that it will not hold water. Put the box in a warm place (not at any time over 70° or 80° Fahrenheit),[1] and cover it loosely with a board or a pane of glass. Keep the sand or sawdust moist, but not wet, and the seeds will germinate. As soon as any of the seeds, on being dug up, are found to have burst open, sketch one in this condition,[2] noting the manner in which the outer seed-coat is split, and continue to examine the seedlings at intervals of two days, until at least eight stages in the growth of the plantlet have been noted.[3]

[1] Here and elsewhere throughout the book temperatures are expressed in Fahrenheit degrees, since with us, unfortunately, the Centigrade scale is not the familiar one, outside of physical and chemical laboratories.

[2] The student need not feel that he is expected to make finished drawings to record what he sees, but some kind of careful sketch, if only the merest outline, is indispensable. Practice and study of the illustrations hereafter given will soon impart some facility even to those who have had little or no instruction in drawing. Consult here Figs. 9 and 89.

[3] The class is not to wait for the completion of this work (which may, if desirable, be done by each pupil at home), but is to proceed at once with the examination of the squash seed and of other seeds, as directed in the following sections, and to set some beans, peas, and corn to sprouting, so that they may be studied at the same time with the germinating squashes.

Observe particularly how the sand is pushed aside by the rise of the young seedlings. Suggest some reason for the manner in which the sand is penetrated by the rising stem.

2. Examination of the Squash Seed. — Make a sketch of the dry seed, natural size. Note the little scar at the pointed end of the seed where the latter was attached to its place of growth in the squash. Label this *hilum*.

Note the little hole in the hilum; it is the *micropyle*, seen most plainly in a soaked seed. (If there are two depressions on the hilum the deeper one is the micropyle.)

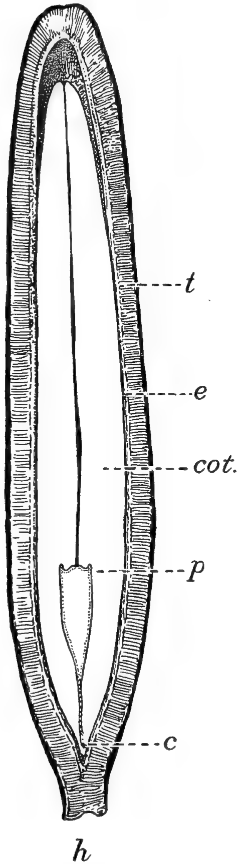


FIG. 1. — Lengthwise Section of a Squash Seed. (Magnified about five times.)

Describe the color and texture of the outer coating of the seed. With a scalpel or a very sharp knife cut across near the middle a seed that has been soaked in water for twenty-four hours. Squeeze one of the portions, held edgewise between the thumb and finger, in such a way as to separate slightly the halves into which the contents of the seed is naturally divided. Examine with the magnifying glass the section thus treated, make a sketch of it, and label the shell or covering of the seed and the kernel within this.

Taking another soaked seed, chip away the white outer shell, called the *testa*, and observe the thin, greenish inner skin (Fig. 1, *e*), with which the kernel of the seed is closely covered.[1]

Strip this off and sketch the uncovered kernel or *embryo*. Note that at one end it tapers to a point. This pointed portion, known as the *hypocotyl*, will develop after the seed sprouts into the stem of the plantlet, like that shown at *c* in Fig. 2.

Split the halves of the kernel entirely apart from each other,

[1] See footnote 2 to Sect. 18.

noticing that they are only attached for a very little way next to the hypocotyl, and observe the thickness of the halves and the slight unevenness of the inner surfaces. These halves are called seed-leaves or *cotyledons*.

Have ready some seeds which have been soaked for twenty-four hours and then left in a loosely covered jar on damp blotting paper at a temperature of 70° or over until they have begun to sprout.

Split one of these seeds apart, separating the cotyledons, and observe, at the junction of these, two very slender pointed objects, the rudimentary leaves of the *plumule* or first bud (Fig. 1, *p*).

3. Examination of the Bean. —Study the seed, both dry and after twelve hours' soaking, in the same general way in which the squash seed has just been examined.[1]

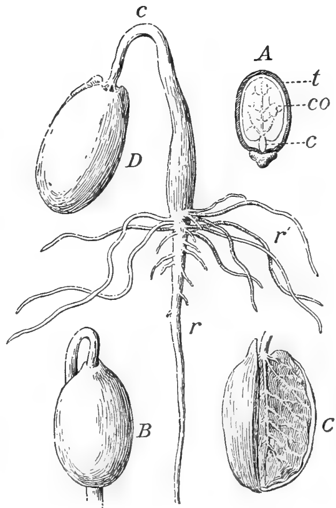


FIG. 2.—The Castor Bean and its Germination.

A, longitudinal section of ripe seed; *t*, testa; *co*, cotyledon; *c*, hypocotyl; *B*, sprouting seed covered with endosperm; *C*, same, with half of endosperm removed; *D*, seedling; *r*, primary root; *r'*, secondary roots; *c*, arch of hypocotyl.

Notice the presence of a distinct plumule, consisting of a pair of rudimentary leaves between the cotyledons, just where they are joined to the top of the hypocotyl. In many seeds (as the pea) the plumule does not show distinct leaves. But in all cases the plumule contains the *growing point*, the tip of the stem from which all the upward growth of the plant is to proceed.

Make a sketch of these leaves as they lie in place on one of the cotyledons, after the bean has been split open.

[1] The larger the variety of bean chosen, the easier it will be to see and sketch the several parts. The large red kidney bean, the horticultural bean, or the lima bean will do well for this examination.

Note the cavity in each cotyledon caused by the pressure of the plumule and of the hypocotyl.

4. Examination of the Pea. — There are no very important points of difference between the bean and pea, so far as the structure of the seed is concerned, but the student should rapidly dissect a few soaked peas to get an idea of the appearance of the parts, since he is to study the germination of peas in some detail.

Make only one sketch, that of the hypocotyl as seen in position after the removal of the seed-coats.[1]

5. Germination of the Bean or the White Lupine, the Pea, and the Grain of Corn. — Soak some beans or lupine seeds as directed in Section 3, plant them,[2] and make a series of sketches on the same general plan as those in Fig. 9.

Follow the same directions with some peas and some corn. In the case of the corn, make six or more sketches at various stages to illustrate the growth of the plumule and the formation of roots; first a main root from the base of the hypocotyl, then others more slender from the same region, and later on still others from points higher up on the stem (see Fig. 15). The student may be able to discover what becomes of the large outer part of the embryo. This is really the single cotyledon of the corn (Fig. 6). It does not as a whole rise above ground, but most of it remains in the buried grain, and acts as a digesting and absorbing organ through which the endosperm or food stored outside of the embryo is transferred into the growing plant, as fast as it can be made liquid for that purpose.

6. Germination of the Horse-Chestnut. — Plant some seeds of the horse-chestnut or the buckeye, study their mode of germination, and observe the nature and peculiar modifications of the parts.

Consult Gray's *Structural Botany*, Vol. I, pp. 19, 20.

7. Conditions Requisite for Germination. — When we try to enumerate the external conditions which can affect

[1] The teacher will find excellent sketches of most of the germinating seeds described in the present chapter in Miss Newell's *Outlines of Lessons in Botany*, Part I.

[2] The pupil may economize space by planting the new seeds in boxes from which part of the earlier planted seeds have been dug up for use in sketching, etc.

germination, we find that the principal ones are heat, moisture, and presence of air. A few simple experiments will show what influence these conditions exert.

8. Temperature. — Common observation shows that a moderate amount of warmth is necessary for the sprouting of seeds. Every farmer or gardener knows that during a cold spring many seeds, if planted, will rot in the ground. But a somewhat exact experiment is necessary to show what is the best temperature for seeds to grow in, and whether variations in the temperature make more difference in the quickness with which they begin to germinate or in the total per cent which finally succeed.

EXPERIMENT I

Relation of Temperature to Germination. — Prepare at least four teacups or tumblers, each with wet soft paper packed in the bottom to a depth of nearly an inch. Have a tightly fitting cover over each. Put in each vessel the same number of soaked peas. Stand the vessels with their contents in places where they will be exposed to different, but fairly constant, temperatures, and observe the several temperatures carefully with a thermometer. Take pains to keep the tumblers in the warm places from drying out, so that their contents will not be less moist than that of the others. The following series is merely suggested, — other values may be found more convenient. Note the rate of germination in each place and record in tabular form as follows:

No. of seeds sprouted in	24 hrs.	48 hrs.	72 hrs.	96 hrs.	etc.
At 32°,	——	——	——	——	——
At 50°,	——	——	——	——	——
At 70°,	——	——	——	——	——
At 90°,[1]	——	——	——	——	——

[1] For the exact regulation of the temperatures a thermostat (see *Handbook*) is desirable. If one is available, a maximum temperature of 100° or over should be tried.

9. Moisture. — What was said in the preceding section in regard to temperature applies also to the question of the best conditions for germination as regards the supply of moisture. The soil in which seeds grow out of doors is always moist; it rests with the experimenter to find out approximately what is the best amount of moisture.

EXPERIMENT II[1]

Relation of Water to Germination. — Arrange seeds in several vessels as follows:

In the first put blotting paper that is barely moistened; on this put some dry seeds.

In the second put blotting paper that has been barely moistened; on this put seeds that have been soaked for twenty-four hours.

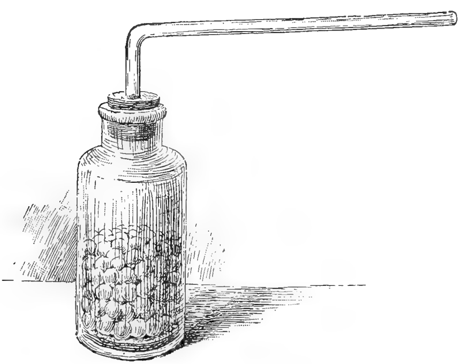


FIG. 3. — Soaked Peas in Stoppered Bottle, ready for Exhaustion of Air.

In the third put water enough to soak the paper thoroughly; use soaked seeds.

In the fourth put water enough to half cover the seeds.

Place the vessels where they will have same temperature and note the time of germination.

Tabulate your results as in the previous experiment.

10. Relation of the Air Supply to Germination. — If we wish to see how soaked seeds will behave with hardly any air supply, it is necessary to place them in a bottle arranged

[1] This may be made a home experiment.

as shown in Fig. 3, exhaust the air by connecting the glass tube with an air-pump, which is then pumped vigorously, and seal the tube while the exhaustion is going on. The sealing is best done by holding a Bunsen flame under the middle of the horizontal part of the tube. A much easier experiment, which is nearly as satisfactory, can, however, be performed without the air-pump.

EXPERIMENT III

Will Seeds Germinate well without a Good Supply of Air? — Place some soaked seeds on damp blotting paper in the bottom of a bottle, using seeds enough to fill it three-quarters full, and close tightly with a rubber stopper.

Place a few other seeds of the same kind in a second bottle; cover loosely.

Place the bottles side by side, so that they will have the same conditions of light and heat. Watch for results, and tabulate as in previous experiments.

Most seeds will not germinate under water, but those of the sunflower will do so, and therefore Exp. III may be varied in the following manner:

Remove the shells carefully from a considerable number of sunflower seeds.[1] Try to germinate one lot of these in water which has been boiled in a flask to remove the air, and then cooled in the same flask. Over the water, with the seeds in it, a layer of cotton-seed oil about a half inch deep is poured, to keep the water from contact with air. In this bottle then there will be only seeds and air-free water. Try to germinate another lot of seeds in a bottle half filled with ordinary water, also covered with cotton-seed oil. Results?

11. Germination involves Chemical Changes.— If a thermometer is inserted into a jar of sprouting seeds, for

[1] These are really fruits, but the distinction is not an important one at this time.

instance peas, in a room at the ordinary temperature, the peas will be found to be warmer than the surrounding air. This rise of temperature is at least partly due to the absorption from the air of that substance in it which supports the life of animals and maintains the burning of fires, namely, *oxygen*.

The union of oxygen with substances with which it can combine, that is with those which will burn, is called *oxidation*. This kind of chemical change is universal in plants and animals while they are in an active condition, and the energy which they manifest in their growth and movements is as directly the result of the oxidation going on inside them as the energy of a steam engine is the result of the burning of coal or other fuel under its boiler. In the sprouting seed much of the energy produced by the action of oxygen upon oxidizable portions of its contents is expended in producing growth, but some of this energy is wasted by being transformed into heat which escapes into the surrounding soil. It is this escaping heat which is detected by a thermometer thrust into a quantity of germinating seeds.

EXPERIMENT IV

Effect of Germinating Seeds upon the Surrounding Air. — When Exp. III has been finished, remove a little of the air from above the peas in the first bottle. This can easily be done with a rubber bulb attached to a short glass tube. Then bubble this air through some clear, filtered limewater. Also blow the breath through some limewater by aid of a short glass tube. Explain any similarity in results obtained. (Carbon dioxide turns limewater milky.) Afterwards insert into the air above the peas in the same bottle a lighted pine splinter, and note the effect upon its flame.

12. Other Proofs of Chemical Action. — Besides the proof of chemical changes in germinating seeds just described, there are other kinds of evidence to the same effect.

Malt, which is merely sprouted barley with its germination permanently stopped at the desired point by the application of heat, tastes differently from the unsprouted grain, and can be shown by chemical tests to have suffered a variety of changes. If you can get unsprouted barley and malt, taste both and see if you can decide what substance is more abundant in the malt.

Germinating kernels of corn undergo great alterations in their structure; the starch grains are gradually eaten away until they are ragged and full of holes and finally disappear.

13. The Embryo and its Development. — The miniature plant, as it exists ready formed and alive but inactive in the seed, is called the *embryo*. In the seeds so far examined, practically the entire contents of the seed-coats consist of the embryo, but this is not the case with the great majority of seeds, as will be shown in the following chapter.

CHAPTER II

STORAGE OF FOOD IN THE SEED

14. Food in the Embryo. — Squash seeds are not much used for human food, though both these and melon seeds are occasionally eaten in parts of Europe; but beans and peas are important articles of food. Whether the material accumulated in the cotyledons is an aid to the growth of the young plant may be learned from a simple experiment.

15. Mutilated and Perfect Seedlings. — One of the best ways in which to find out the importance and the special use of any part of a plant is to remove the part in question and see how the plant behaves afterward.

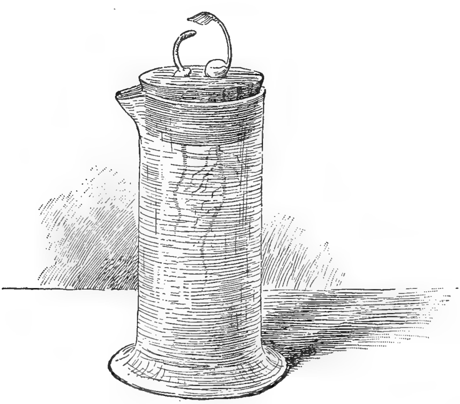


FIG. 4. — Germinating Peas, growing in Water, one deprived of its Cotyledons.

EXPERIMENT V[1]

Are the Cotyledons of a Pea of any Use to the Seedling? — Sprout several peas on blotting paper. When the plumules appear, carefully cut away the cotyledons from some of the seeds. Place on a perforated cork, as shown in Fig. 4, one or two seedlings from

[1] May be a home experiment.

which the cotyledons have been cut, and as many which have not been mutilated, and allow the roots to extend into the water. Let them grow for some days, or even weeks, and note results.

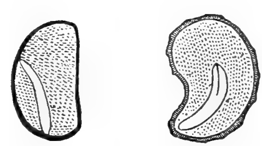
16. Food stored in Seeds in Relation to Growth after Germination. — If two kinds of seeds of somewhat similar character, one kind large and the other small, are allowed to germinate and grow side by side, some important inferences may be drawn from their relative rate of growth.

EXPERIMENT VI[1]

Does the Amount of Material in the Seed have anything to do with the Rate of Growth of the Seedling? — Germinate ten or more clover seeds, and about the same number of peas, on moist blotting paper under a bell-jar. After they are well sprouted, transfer both kinds of seeds to fine cotton netting, stretched across wide-mouthed jars nearly full of water. The roots should dip into the water, but the seeds must not do so. Allow the plants to grow until the peas are from four to six inches high.

Some of the growth in each case depends on material gathered from the air and water, but most of it, during the very early life of the plant, is due to the reserve material stored in the seed. Where is it in the seeds so far studied? Proof?

17. Storage of Food outside of the Embryo. — In very many cases the cotyledons contain little food, but there is a supply of it stored in the seed beside or around them (Figs. 2, 5, and 6).



I II

FIG. 5. — Seeds with Endosperm, Longitudinal Sections.

I, asparagus (magnified).
II, poppy (magnified).

18. Examination of the Four-o'clock Seed. — Examine the external surface of a seed[2] of the four-o'clock, and try the hardness of

[1] May be a home experiment. [2] Strictly speaking, a fruit.

the outer coat by cutting it with a knife. From seeds which have been soaked in water at least twenty-four hours peel off the coatings and sketch the kernel. Make a cross-section of one of the soaked seeds which has not been stripped of its coatings, and sketch the section as seen with the magnifying glass, to show the parts, especially the two cotyledons, lying in close contact and encircling the white, starchy-looking *endosperm*.[1]

The name *endosperm* is applied to food stored in parts of the seed other than the embryo.[2] With a mounted needle pick out the little almost spherical mass of endosperm from inside the cotyledons of a seed which has been deprived of its coats, and sketch the embryo, noting how it is curved so as to enclose the endosperm almost completely.

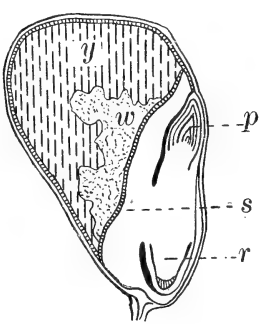


FIG. 6. — Lengthwise Section of Grain of Corn. (Magnified about three times.)

y, yellow, oily part of endosperm; *w*, white, starchy part of endosperm; *p*, plumule; *s*, the shield (cotyledon), in contact with the endosperm for absorption of food from it; *r*, the primary root.

19. Examination of the Kernel of Indian Corn. — Soak some grains of large yellow field corn[3] for about three days.

Sketch an unsoaked kernel, so as to show the grooved side, where the germ lies. Observe how this groove has become partially filled up in the soaked kernels.

Remove the thin, tough skin from one of the latter, and notice its transparency. This skin — the bran of unsifted corn meal — does not exactly correspond to the testa and inner coat of ordinary seeds, since the kernel of corn, like all other grains (and like the seed of the four-o'clock), represents not merely the seed, but also the seed-vessel in which it was formed and grew, and is therefore a fruit.

[1] Buckwheat furnishes another excellent study in seeds with endosperm. Like that of the four-o'clock, it is, strictly speaking, a fruit; so also is a grain of corn.

[2] In the squash seed the green layer which covered the embryo represents the remains of the endosperm.

[3] The varieties with long, flat kernels, raised in the Middle and Southern States under the name of "dent corn," are the best.

Cut sections of the soaked kernels, some transverse, some lengthwise and parallel to the flat surfaces, some lengthwise and at right angles to the flat surfaces. Try the effect of staining some of these sections with iodine solution.

Make a sketch of one section of each of the three kinds, and label the dirty white portion, of cheesy consistency, *embryo;* and the yellow portions, and those which are white and floury, *endosperm.*

Chip off the endosperm from one kernel so as to remove the embryo free from other parts.[1] Notice its form, somewhat triangular in outline, sometimes nearly the shape of a beechnut, in other specimens nearly like an almond.

Estimate what proportion of the entire bulk of the soaked kernel is embryo.

Split the embryo lengthwise so as to show the slender, somewhat conical plumule.[2]

20. Corn Seedlings deprived of Endosperm. — An experiment parallel to No. V serves to show the function and the importance of the endosperm of Indian corn.

EXPERIMENT VII

Of how much Use to the Corn Seedling is the Endosperm? — Sprout kernels of corn on blotting paper. When they get fairly started, cut away the endosperm carefully from several of the seeds. Suspend on mosquito netting on the surface of water in the same jar two or three seedlings which have had their endosperm removed, and as many which have not been mutilated. Let them grow for some weeks, and note results.

21. Starch. — Most common seeds contain starch. Every one knows something about the appearance of ordi-

[1] The embryo may be removed with great ease from kernels of rather mature green corn. Boil the corn for about twenty minutes on the cob, then pick the kernels off one by one with the point of a knife. They may be preserved indefinitely in alcohol of 50 or 75%.

[2] The teacher may well consult Figs. 56–61, inclusive, in Gray's *Structural Botany.*

nary commercial starch as used in the laundry, and as sold for food in packages of cornstarch. When pure it is characterized not only by its lustre, but also by its peculiar velvety feeling when rubbed between the fingers.

22. The Starch Test. — It is not always easy to recognize at sight the presence of starch as it occurs in seeds, but it may be detected by a very simple chemical test, namely, the addition of a solution of iodine.[1]

EXPERIMENT VIII[2]

Examination of Familiar Seeds with Iodine. — Cut in two with a sharp knife the seeds to be experimented on, then pour on each, drop by drop, some of the iodine solution. Only a little is necessary; sometimes the first drop is enough.

If starch is present, a blue color (sometimes almost black) will appear. If no color is obtained in this way, boil the pulverized seeds for a moment in a few drops of water, and try again.

Test in this manner corn, wheat (in the shape of flour), oats (in oatmeal), barley, rice, buckwheat, flax, rye, sunflower, four-o'clock, morning-glory, mustard seed, beans, peanuts, Brazil-nuts, hazelnuts, and any other seeds that you can get. Report your results in tabular form as follows:

MUCH STARCH	LITTLE STARCH	NO STARCH
Color: blackish or dark blue.	Color: pale blue or greenish.	Color: brown, orange, or yellowish.

23. Microscopical Examination of Starch.[3] — Examine starch in water with a rather high power of the microscope (not less than 200 diameters).

[1] The tincture of iodine sold at the drug-stores will do, but the solution prepared as directed in the *Handbook* answers better. This may be made up in quantity, and issued to the pupils in drachm vials, to be taken home and used there, if the experimenting must be done outside of the laboratory or the schoolroom.

[2] May be a home experiment.

[3] At this point the teacher should give a brief illustrated talk on the construction and theory of the compound microscope.

Pulp scraped from a potato, that from a canna rootstock, wheat flour, the finely powdered starch sold under the commercial name of "cornstarch" for cooking, oatmeal, and buckwheat finely powdered in a mortar, will furnish excellent examples of the shape and markings of starch grains. Sketch all of the kinds examined, taking pains to bring out the markings.[1] Compare the sketches with Figs. 7 and 8.

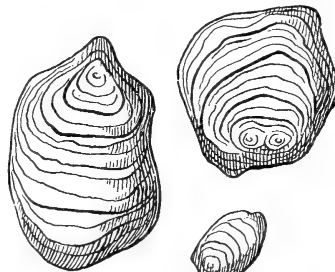


FIG. 7. — Canna Starch. (Magnified 300 diameters.)

With a medicine-dropper or a very small pipette run in a drop of iodine solution under one edge of the cover-glass, at the same time withdrawing a little water from the margin opposite by touching to it a bit of blotting paper.

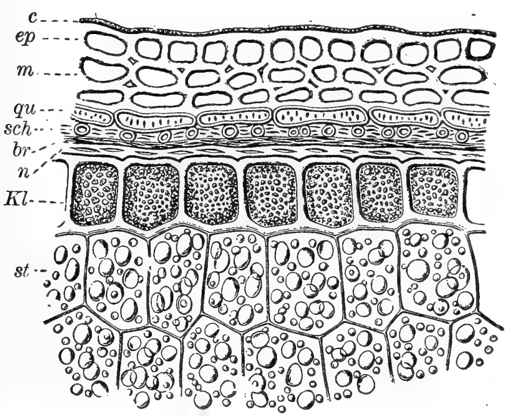


FIG. 8. — Section through Exterior Part of a Grain of Wheat.

c, cuticle or outer layer of bran; *ep*, epidermis; *m*, layer beneath epidermis; *qu*, *sch*, layers of hull next to seed-coats; *br*, *n*, seed-coats; *Kl*, layer containing proteid grains; *st*, cells of the endosperm filled with starch. (Greatly magnified.)

[1] The markings will be seen more distinctly if care is taken not to admit too much light to the object. Rotate the diaphragm beneath the stage of the microscope, or otherwise regulate the supply of light, until the opening is found which gives the best effect.

Examine again and note the blue coloration of the starch grains and the unstained or yellow appearance of other substances in the field. Cut very thin slices from beans, peas, or kernels of corn; mount in water, stain as above directed, and draw as seen under the microscope. Compare with Figs. 7 and 8.[1] Note the fact that the starch is not packed away in the seeds in bulk, but that it is enclosed in little chambers or *cells*.

24. Plant-Cells. — Almost all the parts of the higher plants are built up of little separate portions called *cells*. The cell is the unit of plant-structure, and bears something the same relation to the plant of which it is a part that one cell of a honeycomb does to the whole comb. But this comparison is not a perfect one, for neither the waxen wall of the honeycomb-cell nor the honey within it is alive, while every plant-cell is or has been alive. And even the largest ordinary honeycomb consists of only a few hundred cells, while a large tree is made up of very many miillons of cells. The student must not conceive of the cell as merely a little chamber or enclosure. *The living, more or less liquid, or mucilage-like, or jelly-like substance known as protoplasm, which forms a large portion of the bulk of living and growing cells, is the all-important part of such a cell.* Professor Huxley has well called this substance "the physical basis of life." Cells are of all shapes and sizes, from little spheres a ten-thousandth of an inch or less in diameter to slender tubes, such as fibers of cotton, several inches long. To get an idea of the appearance of some rather large cells, scrape a little pulp from a ripe, mealy apple, and examine it first with

[1] The differentiation between the starch grains, the other cell-contents, and the cell-walls will appear better in the drawings if the starch grains are sketched with blue ink.

a strong magnifying glass, then with a moderate power of the compound microscope. To see how dead, dry cell-walls, with nothing inside them, look, examine (as before) a very thin slice of elder pith, sunflower pith, or pith from a dead cornstalk. Look also at the figures in Chapter VI of this book. Notice that the simplest plants (Chapter XX) consist of a single cell each. The study of the structure of plants is the study of the forms which cells and groups of cells assume, and the study of plant physiology is the study of what cells and cell combinations do.

25. Absorption of Starch from the Cotyledons. — Examine with the microscope, using a medium power, soaked beans and the cotyledons from seedlings that have been growing for three or four weeks. Stain the sections with iodine solution, and notice how completely the clusters of starch grains that filled most of the cells of the unsprouted cotyledons have disappeared from the shriveled cotyledons of the seedlings. A few grains may be left, but they have lost their sharpness of outline.

26. Oil. — The presence of oil in any considerable quantity in seeds is not as general as is the presence of starch, though in many common seeds there is a good deal of it.

Sometimes the oil is sufficiently abundant to make it worth while to extract it by pressure, as is done with flax-seed, cotton-seed, the seeds of some plants of the cress family, the "castor bean," and other seeds.

27. Dissolving Oil from Ground Seeds. — It is not possible easily to show a class how oil is extracted from seeds by pressure; but there are several liquids which readily dissolve oils and yet have no effect on starch and most of the other constituents of seeds.

EXPERIMENT IX

Extraction of Oil by Ether or Benzine. — To a few ounces of ground flaxseed add an equal volume of ether or benzine. Let it stand ten or fifteen minutes and then filter. Let the liquid stand in a saucer or evaporating dish in a good draught till it has lost the odor of the ether or benzine.

Describe the oil which you have obtained.

Of what use would it have been to the plant?

If the student wishes to do this experiment at home for himself, he should bear in mind the following:

Caution. — Never handle benzine or ether near a flame or stove.

A much simpler experiment to find oil in seeds may readily be performed by the pupil at home. Put the material to be studied, *e.g.*, flaxseed meal, corn meal, wheat flour, cotton-seed meal, buckwheat flour, oatmeal, and so on, upon little labeled pieces of white paper, one kind of flour or meal on each bit of paper. Place all the papers, with their contents, on a perfectly clean plate, free from cracks, or on a clean sheet of iron, and put this in an oven hot enough nearly (but not quite) to scorch the paper. After half an hour remove the plate from the oven, shake off the flour or meal from each paper, and note the results, a more or less distinct grease spot showing the presence of oil, or the absence of any stain that there was little or no oil in the seed examined.

28. Albuminous Substances. — Albuminous substances or *proteids* occur in all seeds, though often only in small quantities. They have nearly the same chemical composition as white of egg and the curd of milk among animal substances, and are essential to the plant, since the living and growing parts of all plants contain large quantities of proteid material.

Sometimes the albuminous constituents of the seed occur in more or less regular grains (Fig. 8, at *Kl*).

But much of the proteid material of seeds is not in any

form in which it can be recognized under the microscope. One test for its presence is the peculiar smell which it produces in burning. Hair, wool, feathers, leather, and lean meat all produce a well-known sickening smell when scorched or burned, and the similarity of the proteid material in such seeds as the bean and pea to these substances is shown by the fact that scorching beans and similar seeds give off the familiar smell of burnt feathers.

29. Chemical Tests for Proteids. — All proteids (and very few other substances) are turned yellow by nitric acid, and this yellow color becomes deeper or even orange when the yellowish substance is moistened with ammonia. They are also turned yellow by iodine solution. Most proteids are turned more or less red by the solution of nitrate of mercury known as Millon's reagent.[1]

EXPERIMENT X

Detection of Proteids in Seeds. — Extract the germs from some soaked kernels of corn and bruise them; soak some wheat-germ meal for a few hours in warm water, or wash the starch out of wheat-flour dough; reserving the latter for use, place it in a white saucer or porcelain evaporating dish, and moisten well with Millon's reagent or with nitric acid; examine after fifteen minutes.

30. The Brazil-Nut as a Typical Oily Seed. — Not many familiar seeds are as oily as the Brazil-nut. Its large size makes it convenient for examination, and the fact that this nut is good for human food makes it the more interesting to investigate the kinds of plant-food which it contains.

[1] See *Handbook*.

EXPERIMENT XI

Testing Brazil-Nuts for Plant-Foods. — Crack fifteen or twenty Brazil-nuts, peel off the brown coating from the kernel of each, and then grind the kernels to a pulp in a mortar. Shake up this pulp with ether, pour upon a paper filter, and wash with ether until the washings when evaporated are nearly free from oil. The funnel containing the filter should be kept covered as much as possible until the washing is finished. Evaporate the filtrate to procure the oil, which may afterwards be kept in a glass-stoppered bottle. Dry the powder which remains on the filter and keep it in a wide-mouthed bottle. Test portions of this powder for proteids and for starch. Explain the results obtained.

31. Other Constituents of Seeds. — Besides the substances above suggested, others occur in different seeds. Some of these are of use in feeding the seedling, others are of value in protecting the seed itself from being eaten by animals or in rendering it less liable to decay. In such seeds as that of the nutmeg, the essential oil which gives it its characteristic flavor probably makes it unpalatable to animals and at the same time preserves it from decay.

Date seeds are so hard and tough that they cannot be eaten and do not readily decay. Lemon, orange, horse-chestnut and buckeye seeds are too bitter to be eaten, and the seeds of the apple, cherry, peach, and plum are somewhat bitter.

The seeds of larkspur, thorn-apple,[1] croton, the castor-oil plant, nux vomica, and many other kinds of plants contain active poisons.

[1] Datura, commonly called "Jimpson weed."

CHAPTER III

MOVEMENTS, DEVELOPMENT, AND MORPHOLOGY OF THE SEEDLING

32. How the Seedling breaks Ground. — As the student has already learned by his own observations, the seedling does not always push its way straight out of the ground. Corn, like all the other grains and grasses, it is true, sends a tightly rolled, pointed leaf vertically upward into the air. But the other seedlings examined usually will not be found to do anything of the sort. The squash seedling is a good one in which to study what may be called the arched hypocotyl type of germination. If the seed when planted is laid hori-

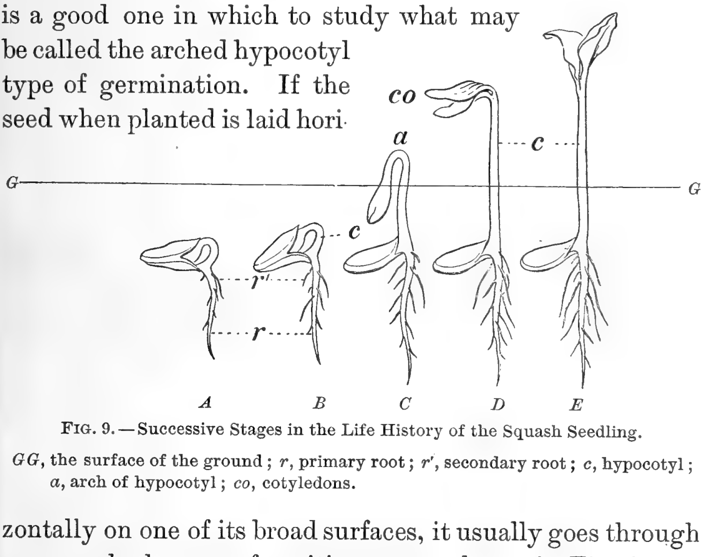


FIG. 9. — Successive Stages in the Life History of the Squash Seedling.

GG, the surface of the ground; *r*, primary root; *r'*, secondary root; *c*, hypocotyl; *a*, arch of hypocotyl; *co*, cotyledons.

zontally on one of its broad surfaces, it usually goes through some such changes of position as are shown in Fig. 9.

The seed is gradually tilted until, at the time of their emergence from the ground (at *C*), the cotyledons are almost vertical. The only part above the ground-line *G*, *G*, at this period, is the arched hypocotyl. Once out of ground, the cotyledons soon rise, until (at *E*) they are again vertical, but with the other end up from that which stood highest in *C*. Then the two cotyledons separate until they once more lie horizontal, pointing away from each other.

Can you suggest any advantage which the plant derives from having the cotyledons dragged out of the ground rather than having them pushed out, tips first?

33. Cause of the Arch. — It is evident that a flexible object like the hypocotyl, when pushed upward through the earth, might easily be bent into an arch or loop. Whether the shape which the hypocotyl assumes is wholly caused by the resistance of the soil can best be ascertained by an experiment.

EXPERIMENT XII

Is the Arch of the Hypocotyl due to the Pressure of the Soil on the Rising Cotyledons? — Sprout some squash seeds on wet paper under a bell-glass, and when the root is an inch or more long, hang several of the seedlings, roots down, in little stirrups made of soft twine, attached by beeswax and rosin mixture to the inside of the upper part of a bell-glass. Put the bell-glass on a large plate or a sheet of glass on which lies wet paper to keep the air moist. Note whether the seedlings form hypocotyl arches at all and, if so, whether the arch is more or less perfect than that formed by seedlings growing in earth, sand, or sawdust.

34. What pushes the Cotyledons up? — A very little study of any set of squash seedlings, or even of Fig. 9, is

sufficient to show that the portion of the plant where roots and hypocotyl are joined neither rises nor sinks, but that the plant grows both ways from this part (a little above r' in Fig. 9, *A* and *B*). It is evident that as soon as the hypocotyl begins to lengthen much it must do one of two things: either push the cotyledons out into the air or else force the root down into the ground as one might push a stake down. What changes does the plantlet undergo, in passing from the stage shown at *A* to that of *B* and of *C*, making it harder and harder for the root to be thrust downward?

35. Use of the Peg. — Squash seedlings usually (though not always) form a sort of knob on the hypocotyl. This is known as the peg. Study a good many seedlings and try to find out what the lengthening of the hypocotyl, between the peg and the bases of the cotyledons, does for the little plant. Set a lot of squash seeds, hilum down, in moist sand or sawdust and see whether the peg is more or less developed than in seeds sprouted lying on their sides, and whether the cotyledons in the case of the vertically planted seeds usually come out of the ground in the same condition as do those shown in Fig. 9.

36. Discrimination between Root and Hypocotyl. — It is not always easy to decide by their appearance and behavior what part of the seedling is root and what part is hypocotyl. In a seedling visibly beginning to germinate, the sprout, as it is commonly called, which projects from the seed might be either root or hypocotyl or might consist of both together, so far as its appearance is concerned. A microscopic study of the cross-section of a root, compared with one of the hypocotyl, would show decided differences

of structure between the two. Their mode of growth is also different, as the pupil may infer after he has tried Exp. XIV.

37. Discrimination by Staining. — For some reason, perhaps because the skin or epidermis of the young root is not so water-proof as that of the stem, the former stains more easily than the latter does.

EXPERIMENT XIII

The Permanganate Test. — Make a solution of potassium permanganate in water, by adding about four parts, by weight, of the crystallized permanganate to 100 parts of water. Drop into the solution seedlings, *e.g.*, of all the kinds that have been so far studied, each in its earliest stage of germination (that is, when the root or hypocotyl has pushed out of the seed half an inch or less), and also at one or two subsequent stages. After the seedlings have been in the solution from three to five minutes, or as soon as the roots are considerably stained, pour off (and save) the solution and rinse the plants with plenty of clear water. Sketch one specimen of each kind, coloring the brown-stained part, which is root, in some way so as to distinguish it from the unstained hypocotyl. Note particularly how much difference there is in the amount of lengthening in the several kinds of hypocotyl examined. Decide whether the peg of the squash seedling is an outgrowth of hypocotyl or of root.

38. Disposition made of the Cotyledons. — As soon as the young plants of squash, bean, and pea have reached a height of three or four inches above the ground it is easy to recognize important differences in the way in which they set out in life.

The cotyledons of the squash increase greatly in surface, acquire a green color and a generally leaf-like appearance, and, in fact, do the work of ordinary leaves. In

such a case as this the appropriateness of the name *seed-leaf* is evident enough, — one recognizes at sight the fact that the cotyledons are actually the plant's first leaves. In the bean the leaf-like nature of the cotyledons is not so clear. They rise out of the ground like the squash cotyledons, but then gradually shrivel away, though they may first turn green and somewhat leaf-like for a time.

In the pea (as in the acorn, the horse-chestnut, and many other seeds) we have quite another plan, the underground type of germination. Here the thick cotyledons no longer rise above ground at all, because they are so gorged with food that they could never become leaves; but the young stem pushes rapidly up from the surface of the soil.

The development of the plumule seems to depend somewhat on that of the cotyledons. The squash seed has cotyledons which are not too thick to become useful leaves, and so the plant is in no special haste to get ready any other leaves. The plumule, therefore, cannot be found with the magnifying glass in the unsprouted seed, and is almost microscopic in size at the time when the hypocotyl begins to show outside of the seed-coats.

In the bean and pea, on the other hand, since the cotyledons cannot serve as foliage leaves, the later leaves must be pushed forward rapidly. In the bean the first pair are already well formed in the seed. In the pea they cannot be clearly made out, since the young plant forms several scales on its stem before it produces any full-sized leaves, and the embryo contains only hypocotyl, cotyledons, and a sort of knobbed plumule, well developed in point of size, representing the lower scaly part of the stem.

39. Root, Stem, and Leaf. — By the time the seedling is well out of the ground it, in most cases, possesses the three kinds of *vegetative organs*, or parts essential to growth, of ordinary flowering plants, *i.e.*, the root, stem, and leaf, or, as they are sometimes classified, root and shoot. All of these organs may multiply and increase in size as the plant grows older, and their mature structure will be studied in later chapters, but some facts concerning them can best be learned by watching their growth from the outset.

40. Young Roots grown for Examination. — Roots growing in sand or ordinary soil cling to its particles so tenaciously that they cannot easily be studied, and those grown in water have not quite the same form as soil-roots. Roots grown in damp air are best adapted for careful study.

41. Elongation of the Root. — We know that the roots of seedlings grow pretty rapidly from the fact that each day finds them reaching visibly farther down into the water or other medium in which they are planted. A sprouted Windsor bean in a vertical thistle-tube will send its root downward fast enough so that ten minutes' watching through the microscope will suffice to show growth. To find out just where the growth goes on requires a special experiment.

EXPERIMENT XIV

In what Portions of the Root does its Increase in Length take Place? — Sprout some peas on moist blotting paper in a loosely covered tumbler. When the roots are one and a half inches or more long, mark them along the whole length with little dots made with a bristle dipped in water-proof India ink, or a fine inked thread stretched on a little bow of whalebone or brass wire.

Transfer the plants to moist blotting paper under a bell-glass or an inverted battery jar and examine the roots at the end of twenty-four hours to see along what portions their length has increased; continue observations on them for several days.

42. Root-Hairs. — Barley, oats, wheat, red clover, or buckwheat seeds soaked and then sprouted on moist blotting paper afford convenient material for studying *root-hairs*. The seeds may be kept covered with a watch-glass or a clock-glass while sprouting. After they have begun to germinate well, care must be taken not to have them kept in too moist an atmosphere, or very few root-hairs will be formed. Examine with the magnifying glass those parts of the root which have these appendages.

Try to find out whether all the portions of the root are equally covered with hairs and, if not, where they are most abundant. (See also Sect. 53.)

The root-hairs in plants growing under ordinary conditions are surrounded by the moist soil and wrap themselves around microscopical particles of earth (Fig. 11). Thus they are able rapidly to absorb through their thin walls the soil-water, with whatever mineral substances it has dissolved in it.

43. The Young Stem. — The hypocotyl, or portion of the stem which lies below the cotyledons, is the earliest formed portion of the stem. Sometimes this lengthens but little; often, however, as the student knows from his own observations, the hypocotyl lengthens enough to raise the cotyledons well above ground, as in Fig. 10.

The later portions of the stem are considered to be divided into successive *nodes*, — places at which a leaf (or

a scale which represents a leaf) appears; and *internodes*,—portions between the leaves.

The student should watch the growth of a seedling bean or pea and ascertain by actual measurements whether the internodes lengthen after they have once been formed, and if so, for how long a time the increase continues.

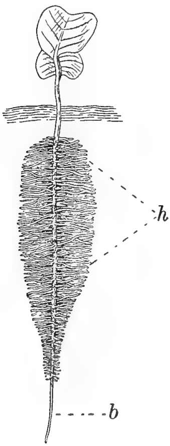


FIG. 10.

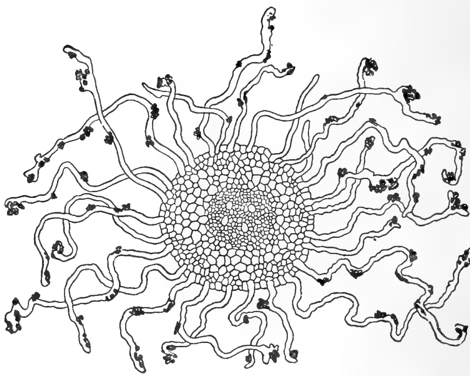


FIG. 11.

FIG. 10.—A Turnip Seedling, with the Cotyledons developed into Temporary Leaves. *h*, root-hairs from the primary root; *b*, bare portion of the root, on which no hairs have as yet been produced.

FIG. 11.—Cross-Section of a Root, a good deal magnified, showing root-hairs attached to particles of soil, and sometimes enwrapping these particles.

44. The First Leaves. — The cotyledons are, as already explained, the first leaves which the seedling possesses,—even if a plumule is found well developed in the seed, it was formed after the cotyledons. In those plants which have so much food stored in the cotyledons as to render these unfit ever to become useful foliage leaves, there is little or nothing in the color, shape, or general appearance

of the cotyledon to make one think it really a leaf, and it is only by studying many cases that the botanist is enabled to class all cotyledons as leaves in their nature, even if they are quite unable to do the ordinary work of leaves. The study of the various forms which the parts or organs of a plant may assume is called *morphology;* it traces the relationship of parts which are really akin to each other, though dissimilar in appearance and often in function. In seeds which have *endosperm*, or food stored outside of the embryo, the cotyledons usually become green and leaf-like, as they do, for example, in the four-o'clock, the morning-glory, and the buckwheat; but in the seeds of the grains (which contain endosperm) a large portion of the single cotyledon remains throughout as a thickish mass buried in the seed. In a few cases, as in the pea, there are scales instead of true leaves formed on the first nodes above the cotyledons, and it is only at about the third node above that leaves of the ordinary kind appear. In the bean and some other plants which in general bear one leaf at a node along the stem, there is a pair produced at the first node above the cotyledons, and the leaves of this pair differ in shape from those which arise from the succeeding portions of the stem.

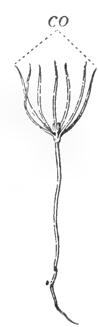


FIG. 12. — Germinating Pine. *co*, cotyledons.

45. Classification of Plants by the Number of their Cotyledons. — In the pine family the germinating seed often displays more than two cotyledons, as shown in Fig. 12; in the majority of common flowering plants the seed contains two cotyledons, while in the lilies, the rushes, the

sedges, the grasses, and some other plants, there is but one cotyledon. Upon these facts is based the division of most flowering plants into two great groups: the *dicotyledonous plants*, which have two seed-leaves, and the *monocotyledonous plants*, which have one seed-leaf. Other important differences nearly always accompany the difference in number of cotyledons, as will be seen later.

46. Tabular Review of Experiments. — Make out a table containing a very brief summary of the experiments thus far performed, as follows:

Number of Experiment	Object sought	Materials and Apparatus	Operations performed	Results	Inferences

47. Review Sketches. — Make out a comparison of the early life histories of all the other seedlings studied, by arranging in parallel columns a series of drawings of each,

like those of Fig. 9, but in vertical series, the youngest of each at the top, thus :

	BEAN	PEA	CORN
FIRST STAGE			
SECOND STAGE			
THIRD STAGE			
FOURTH STAGE			
FIFTH STAGE ETC.			

CHAPTER IV

ROOTS [1]

48. Origin of Roots. — The *primary root* originates from the lower end of the hypocotyl, as the student learned from his own observations on sprouting seeds. The branches of the primary root are called *secondary roots*, and the branches of these are known as *tertiary roots*. Those roots which occur on the stem or in other unusual places are known as *adventitious roots*. The roots which form so readily on cuttings of willow, southernwood, tropæolum, French marigold, geranium (pelargonium), tradescantia, and many other plants, when placed in damp earth or water, are adventitious.

49. Aerial Roots. — While the roots of most familiar plants grow in the earth and are known as *soil-roots*, there are others which are formed in the air, called *aerial roots*. They serve various purposes: in some tropical air-plants (Fig. 13) they serve to fasten the plant to the tree on which it establishes itself, as well as to take in water which drips from branches and trunks above them, so that these plants require no soil and grow in mid-air suspended from trees, which serve them merely as supports; [2] many such

[1] To the plant the root is more important than the stem. The author has, however, treated the structure of the latter more fully than that of the root, mainly because the tissues are more varied in the stem and a moderate knowledge of the more complex anatomy of the stem will serve every purpose.

[2] If it can be conveniently managed, the class will find it highly interesting and profitable to visit any greenhouse of considerable size, in which the aerial roots of orchids and aroids may be examined.

air-plants are grown in greenhouses. In such plants as the ivy (Fig. 15) the aerial roots (which are also adventitious) hold the plant to the wall or other surface up which it climbs.

In the Indian corn (Fig. 14) roots are sent out from nodes at some distance above the ground and finally descend until they enter the ground. They serve both to anchor the cornstalk so as to enable it to resist the wind and to supply additional water to the plant.[1] They often produce no rootlets until they reach the ground.

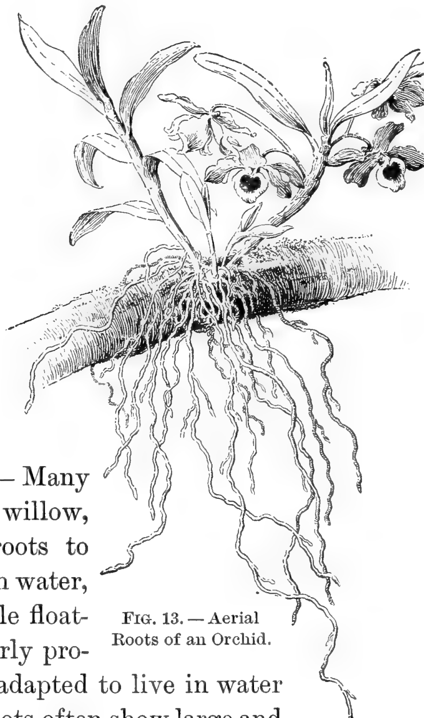


FIG. 13. — Aerial Roots of an Orchid.

50. Water-Roots. — Many plants, such as the willow, readily adapt their roots to live either in earth or in water, and some, like the little floating duckweed, regularly produce roots which are adapted to live in water only. These water-roots often show large and distinct sheaths on the ends of the roots, as, for instance, in the so-called water-hyacinth. This plant is especially interesting for laboratory cultivation from the fact that

[1] Specimens of the lower part of the cornstalk, with ordinary roots and aerial roots, should be dried and kept for class study.

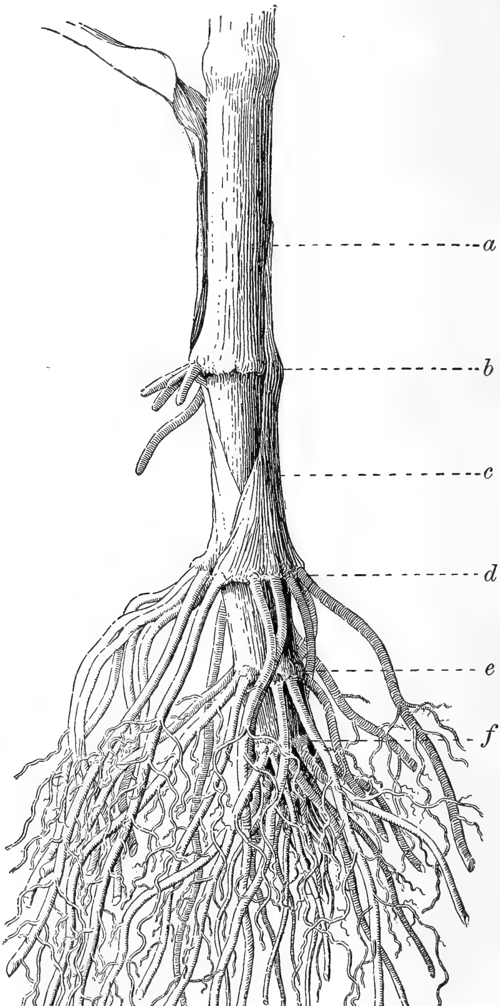


FIG. 14.—Lower Part of Stem and Roots of Indian Corn, showing Aerial Roots ("Brace-Roots").

a, *c*, internodes of the stem; *b*, *d*, *e*, *f*, nodes of various age bearing roots. Most of these started as aerial roots, but all except those from *b* have now reached the earth.

it may readily be transferred to moderately damp soil, and that the whole plant presents curious modifications when made to grow in earth instead of water.

51. Parasitic Roots.[1] — The dodder, the mistletoe, and a good many other *parasites*, live upon nourishment which they steal from other plants, called *hosts*. The parasitic

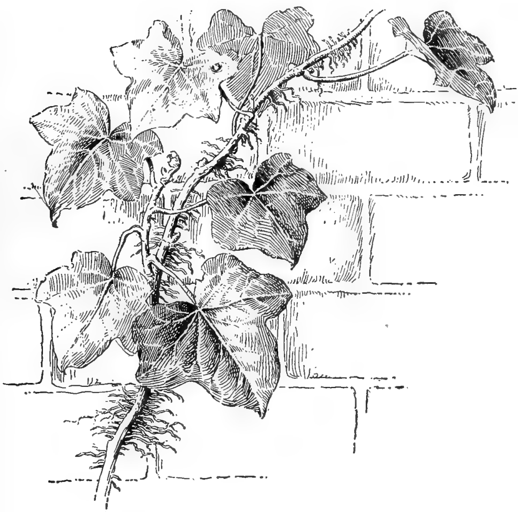


FIG. 15. — Aerial Adventitious Roots of the Ivy.

roots, or *haustoria*, form the most intimate connections with the interior portions of the stem or the root, as the case may be, of the host-plant on which the parasite fastens itself.

In the dodder, as is shown in Fig. 16, it is most interesting to notice how admirably the seedling parasite is adapted to the conditions under which it is to live. Rooted

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. I, pp. 171–213.

at first in the ground, it develops a slender, leafless stem, which, leaning this way and that, no sooner comes into

FIG. 16. — Dodder, growing upon a Golden-Rod Stem.

s, seedling dodder plants, growing in earth; *h*, stem of host; *r*, haustoria or parasitic roots of dodder; *l*, scale-like leaves. *A*, magnified section of a portion of willow stem, showing penetration of haustoria.

permanent contact with a congenial host than it produces haustoria at many points, gives up further growth in its

soil-roots, and grows rapidly on the strength of the supplies of ready-made sap which it obtains from the host.

52. Forms of Roots. — The primary root is that which proceeds like a downward prolongation directly from the lower end of the hypocotyl. In many cases the mature root-system of the plant contains one main root much larger than any of its branches. This is called a *taproot* (Fig. 17).

Such a root, if much thickened, would assume the form

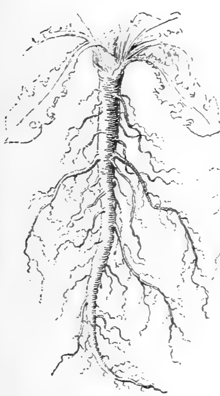


Fig. 17. — A Taproot.

Fig. 18. — Fibrous Roots.

Fig. 19. — Fascicled Roots.

shown in the carrot, parsnip, beet, turnip, salsify, or radish, and is called a fleshy root. Some plants produce *multiple primary* roots, that is, a cluster proceeding from the lower end of the hypocotyl at the outset. If such roots become thickened, like those of the sweet potato and the dahlia (Fig. 19), they are known as *fascicled roots*.

Roots of grasses, etc., are thread-like, and known as *fibrous roots* (Fig. 18).

53. General Structure of Roots. — The structure of the very young root can be partially made out by examining

the entire root with a moderate magnifying power, since the whole is sufficiently translucent to allow the interior as well as the exterior portion to be studied while the root is still alive and growing.

Place some vigorous cuttings of tradescantia or *Zebrina*, which can usually be obtained of a gardener or florist, in a beaker or jar of water.[1] The jar should be as thin and transparent as possible, and it is well to get a flat-sided rather than a cylindrical one. Leave the jar of cuttings in a sunny, warm place. As soon as roots have developed at the nodes and reached the length of three-quarters of an inch or more, arrange a microscope in a horizontal position (see *Handbook*), and examine the tip and adjacent portion of one of the young roots with a power of from twelve to twenty diameters.

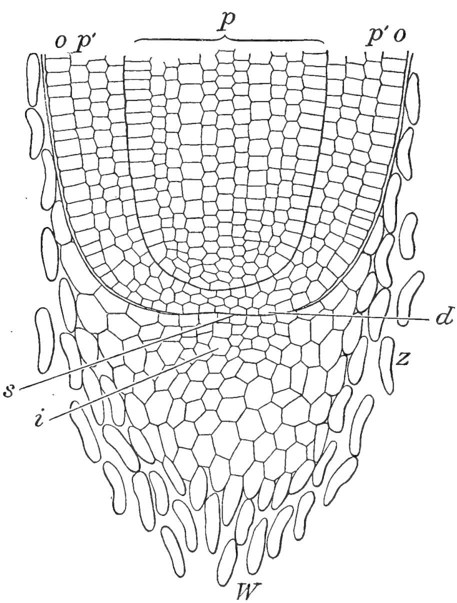


FIG. 20.—Lengthwise Section (somewhat diagrammatic) through Root-Tip of Indian Corn. × about 130.

W, root-cap; *i*, younger part of cap; *z*, dead cells separating from cap; *s*, growing point; *o*, epidermis; *p'*, intermediate layer between epidermis and central cylinder; *p*, central cylinder; *d*, layer from which the root-cap originates.

Note:

(*a*) The root-cap, of loosely attached cells.

(*b*) The central cylinder.

[1] If the tradescantia or *Zebrina* cannot be obtained, roots of seedlings of oats, wheat, or barley, or of red-clover seedlings raised in a large covered cell on a microscope slide, may be used.

(*c*) The cortical portion, a tubular part enclosing the solid central cylinder.

(*d*) The root-hairs, which cover some parts of the outer layer of the cortical portion very thickly. Observe particularly how far toward the tip of the root the root-hairs extend, and where the youngest ones are found.

Make a drawing to illustrate all the points above suggested (*a*, *b*, *c*, *d*). Compare your drawing with Fig. 20. Make a careful study of longitudinal sections through the centers of the tips of very young roots of the hyacinth or the Chinese sacred lily. Sketch one section and compare the sketch with Fig. 20.

Make a study of the roots of any of the common duckweeds, growing in nutrient solution in a jar of water under a bell-glass, and note the curious root-pockets which here take the place of root-caps.

54. Details of Root-Structure. — The plan on which the young root is built has been outlined in Sect. 53. A few further particulars are necessary to an understanding of how the root does its work. On examining Fig. 21 the cylinders of which the root is made up are easily distinguished, and the main constituent parts of each can be made out without much trouble. The epidermis-cells are seen to be somewhat brick-shaped, many of them provided with extensions into root-hairs. Inside the epidermis lie several layers of rather globular, thin-walled cells, and inside these a boundary layer between the cortical or bark portion of the root and the central cylinder. This latter region is especially marked by the presence of certain groups of cells, shown at *w* and *d* and at *b*, the two former serving as channels for air and water, the latter (and *w* also) giving toughness to the root.

Roots of shrubs and trees more than a year old will be found to have increased in thickness by the process

described in Sect. 106, and a section may look quite unlike the young root-section shown in Fig. 21.

55. Examination of the Root of a Shrub or Tree. — Cut thin transverse sections of large and small roots of any hardwood tree[1] and examine them first with a low power of the microscope, as a two-inch objective, to get the general disposition of the parts, then with a higher power, as the half-inch or quarter-inch, for details. With the low power, note:

(*a*) The brown layer of outer bark.

(*b*) The paler layer within this.

(*c*) The woody cylinder which forms the central portion of the root.

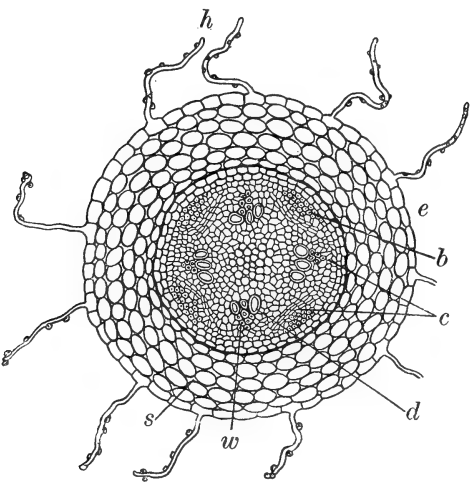


FIG. 21. — Much Magnified Cross-Section of a Very Young Dicotyledonous Root.

h, root-hairs with adhering bits of sand; *e*, epidermis; *s*, thin-walled, nearly globular cells of bark; *b*, hard bast; *c*, cambium; *w*, wood-cells; *d*, ducts.

The distinction between (*b*) and (*c*) is more evident when the section has been exposed to the air for a few minutes and changed somewhat in color. It is a good plan to look with the low power first at a thick section, viewed as an opaque object, and then at a very thin one mounted in water or glycerine, and viewed as a transparent object.

Observe the cut-off ends of the *ducts*, or *vessels*, which serve as passages for air and water to travel through; these appear as holes in the section, and are much more abundant relatively in the young

[1] Young suckers of cherry, apple, etc., which may be pulled up by the roots, will afford excellent material.

than in the older and larger portions of the root. Sketch one section of each kind.

Examine with a higher power (100 to 200 diameters), and note the ends of the thick-walled wood-cells. Compare these with Fig. 72.

Notice the many thinner-walled cells composing stripes radiating away from the center of the root. These bands are the *medullary rays*, whose mode of origin is shown in Fig. 68. Moisten some of the sections with iodine solution,[1] and note where the blue color shows the presence of starch. Split some portions of the root through the middle, cut thin sections from the split surface, and examine with the high power some unstained and some stained with iodine.

Notice the appearance of the wood-cells and the ducts as seen in these sections, and compare with Fig. 58.[2]

56. Structure and Contents of a Fleshy Root. — In some fleshy roots, such as the beet, the morphology of the parts is rather puzzling, since they form many layers of tissue in a single season, showing on the cross-section of the root a series of layers which look a little like the annual rings of trees.

The structure of the turnip, radish, carrot, and parsnip is simpler.

Cut a parsnip across a good deal below the middle, and stand the cut end in eosin solution for twenty-four hours.

Then examine by slicing off successive portions from the upper end. Sketch some of the sections thus made. Cut one parsnip lengthwise and sketch the section obtained. In what portion of the root did the colored liquid rise most readily? The ring of red marks the boundary between the cortical portion and the central cylinder. To which does the main bulk of the parsnip belong? Cut thin transverse sections from an ink-stained parsnip and notice how the medullary rays run out into the cortical portion, and in those sections

[1] If the roots are in their winter condition.

[2] The examination of the minute structure of the root is purposely made very hasty, since the detailed study of the structural elements can be made to better advantage in the stem.

that show it, find out where the secondary roots arise. If possible, peel off the cortical portion from one stained root and leave the central cylinder with the secondary roots attached. Stain one section with iodine, and sketch it. Where is the starch of this root mainly stored?

Test some bits of parsnip for proteids, by boiling them for a minute or two with strong nitric acid.

What kind of plant-food does the taste of cooked parsnips show them to contain? [On no account taste the bits which have been boiled in the poisonous nitric acid.]

57. Storage in Other Roots. — The parsnip is by no means a remarkable plant in its capacity for root-storage. The roots of the yam and the sweet potato contain a good deal of sugar and much more starch than is found in the parsnip. Beet-roots contain so much sugar that a large part of the sugar supply of Europe and an increasing portion of our own supply is obtained from them. Oftentimes the bulk of a fleshy root is exceedingly large as compared with that of the parts of the plant above ground.

The South African plant (*Harpagophytum*, Chapter XXIV) is a good example of this, and another instance is that of a plant,[1] related to the morning-glory and the sweet potato, found in the southeastern United States, which has a root of forty or fifty pounds weight.

Not infrequently roots have a bitter or nauseous taste, as in the case of the chicory, the dandelion, and the rhubarb, and a good many, like the monkshood, the yellow jasmine, and the pinkroot, are poisonous. Can you give any reason why the plant may be benefited by the disgusting taste or poisonous nature of its roots?

[1] *Ipomœa Jalapa.*

58. Use of the Food stored in Fleshy Roots. — The parsnip, beet, carrot, and turnip are *biennial plants;* that is, they do not produce seed until the second summer or fall after they are planted.

The first season's work consists mainly in producing the food which is stored in the roots. To such storage is due their characteristic fleshy appearance. If this root is planted in the following spring, it feeds the rapidly growing stem which proceeds from the bud at its summit, and an abundant crop of flowers and seed soon follows; while the root, if examined in late summer, will be found to be withered, with its store of reserve material quite exhausted.

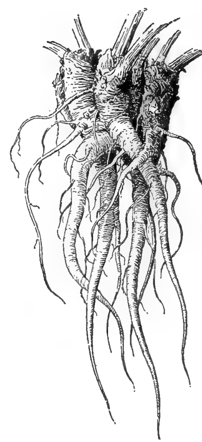


Fig. 22. — Fleshy Roots of Garden Rhubarb. (About one-fifteenth natural size.)

The roots of the rhubarb (Fig. 22), the sweet potato, and of a multitude of other *perennials*, or plants which live for many years, contain much stored plant-food. Many such plants die to the ground at the beginning of winter, and in spring make a rapid growth from the materials laid up in the roots.

59. Extent of the Root-System. — The total length of the roots of ordinary plants is much greater than is usually supposed. They are so closely packed in the earth that only a few of the roots are seen at a time during the process of transplanting, and when a plant is pulled or dug up in the ordinary way, a large part of the whole mass of roots is broken off and left behind. A few plants have

been carefully studied to ascertain the total weight and length of the roots. Those of winter wheat have been found to extend to a depth of seven feet. By weighing the whole root-system of a plant and then weighing a known length of a root of average diameter, the total length of the roots may be estimated. In this way the roots of an oat plant have been calculated to measure about 154 feet; that is, all the roots, if cut off and strung together end to end, would reach that distance.

Single roots of large trees often extend horizontally to great distances, but it is not often possible readily to trace the entire depth to which they extend. One of the most notable examples of an enormously developed root-system is found in the mesquite of the far Southwest and Mexico. When this plant grows as a shrub, reaching the height, even in old age, of only two or three feet, it is because the water supply in the soil is very scanty. In such cases the roots extend down to a depth of sixty feet or more, until they reach water, and the Mexican farmers in digging wells follow these roots as guides. Where water is more plenty, the mesquite forms a good-sized tree, with much less remarkably developed roots.

60. The Absorbing Surface of Roots. — Such aerial roots as are shown in Fig. 13 are usually covered with a spongy absorbent layer, by means of which they retain large quantities of the water which trickles down them during rain-storms. This water they afterwards gradually give up to the plant. Most water-roots (not however those of tradescantia) have no special arrangement for absorbing water except through the general surface of their epidermis. But some water-roots and most soil-roots take in water

mainly through the *root-hairs.* These are delicate, hair-like outgrowths from the epidermis of the root. They are, as seen in Fig. 11, thin-walled tubes, of nearly uniform diameter, closed at the outer end and opening at the inner end into the epidermis-cell from which they spring. The relation of each hair to the epidermis-cell is still better shown in Fig. 23, which represents a very young root-hair and a considerably older one.

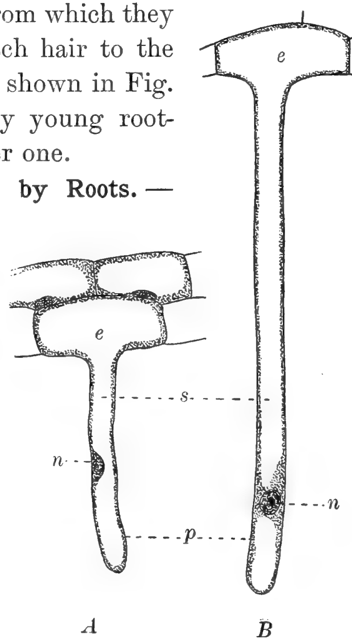


FIG. 23.

A, a very young root-hair; *B*, a much older one (both greatly magnified). *e*, cells of the epidermis of the root; *n*, nucleus; *s*, watery cell-sap; *p*, thicker protoplasm, lining the cell-wall.

61. Absorption of Water by Roots. — Many experiments on the cultivation of corn, wheat, oats, beans, peas, and other familiar plants in water have proved that some plants, at any rate, can thrive very well on ordinary lake, river, or well water, together with the food which they absorb from the air (Chapter XII). Just how much water some kinds of plants give off (and therefore absorb) per day will be discussed when the uses of the leaf are studied. For the present it is sufficient to state that even an annual plant during its lifetime absorbs through the roots very many times its own weight of water. Grasses have been known to take in their weight of water in every twenty-four hours of warm, dry weather. This absorption takes

place mainly through the root-hairs, which the student has examined as they occur in the seedling plant, and which are found thickly clothing the younger and more rapidly growing parts of the roots of mature plants. Some idea of their abundance may be gathered from the fact that on a rootlet of corn grown in a damp atmosphere, and about one-seventeenth of an inch in diameter, 480 root-hairs have been counted on each hundredth of an inch of root. The walls of the root-hairs are extremely thin, and they have no holes or pores visible under even the highest power of the microscope, yet the water of the soil penetrates very rapidly to the interior of the root-hairs. The soil-water brings with it all the substances which it can dissolve from the earth about the plant; and the closeness with which the root-hairs cling to the particles of soil, as shown in Figs. 11 and 21, must cause the water which is absorbed to contain more foreign matter than underground water in general does, particularly since the roots give off enough weak acid from their surface to corrode the surface of stones which they enfold or cover.

62. Osmosis. — The process by which two liquids separated by membranes pass through the latter and mingle, as soil-water does with the liquid contents of root-hairs, is called *osmosis*.

It is readily demonstrated by experiments with thin animal or vegetable membranes.

EXPERIMENT XV

Osmosis as shown in an Egg. — Cement to the smaller end of an egg a bit of glass tubing about six inches long and about three-sixteenths of an inch inside diameter. Sealing-wax or a mixture of equal parts of beeswax and resin melted together will serve for a cement.

Chip away part of the shell from the larger end of the egg, place it in a wide-mouthed bottle or a small beaker full of water, as shown in Fig. 24, then very cautiously pierce a hole through the upper end of the eggshell by pushing a knitting-needle or wire down through the glass tube.

Watch the apparatus for some hours and note any change in the contents of the tube.[1] Explain.

The rise of liquid in the tube is evidently due to water making its way through the thin membrane which lines the eggshell, although this membrane contains no pores visible even under the microscope.

EXPERIMENT XVI

Result of placing Sugar on a Begonia Leaf. — Place a little powdered sugar on the upper surface of a thick begonia leaf under a small bell-glass. Put another portion of sugar or a bit of paper alongside the leaf. Watch for several days. Explain results. The *upper* surface of this leaf contains no pores, even of microscopic size.

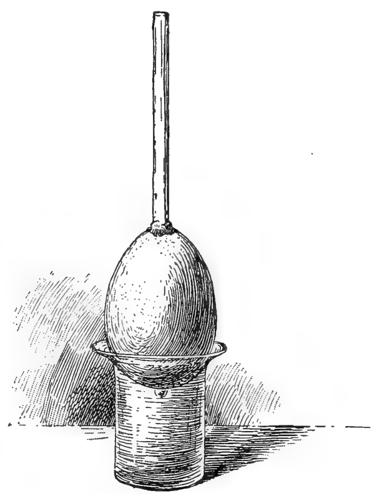


FIG. 24. — Egg on Beaker of Water, to show Osmosis.

63. Inequality of Osmotic Exchange. — The nature of the two liquids separated by any given membrane determines in which direction the greater flow shall take place.

If one of the liquids is pure water and the other

[1] Testing the contents of the beaker with nitrate of silver solution will then show the presence of more common salt than is found in ordinary water. Explain.

is water containing solid substances dissolved in it, the greater flow of liquid will be away from the pure water into the solution, and the stronger or denser the latter, the more unequal will be the flow. This principle is well illustrated by the egg-osmosis experiment. Another important principle is that substances which readily crystallize and are easily soluble, like salt or sugar, pass rapidly through membranes, while jelly-like substances, like white of egg, can hardly pass through them at all.

64. Study of Osmotic Action of Living Protoplasm; Plasmolysis. — The obvious parts of most living and growing plant-cells are a cell-wall, which is a skin or enclosure made of *cellulose*, and the living, active cell-contents or *protoplasm*. Every one is familiar with cellulose in various forms, one of the best examples being that afforded by clean cotton. It is a tough, white or colorless substance, chemically rather inactive. Protoplasm is a substance which differs greatly in its appearance and properties under different circumstances. It is of a very complex nature, so far as its chemical composition is concerned, belonging to the group of proteids and therefore containing not only the elements carbon, hydrogen, and oxygen, common to most organic substances, but nitrogen in addition. The protoplasm in a living cell often consists of several kinds of material; for instance, a rather opaque portion called the nucleus, and a more or less liquid portion lining the cell-walls and extending inward in strands to the nucleus (Fig. 126). Often, in living and active cells, the spaces left between strands and lining are filled with a watery liquid called the *cell-sap*.

The action of the protoplasm in controlling osmosis is well shown by the process known as *plasmolysis*.

Put some living threads of pond-scum (*Spirogyra*) (Chapter XX) into a 4 per cent solution of glycerine in water, a 16 per cent solution of cane sugar, or (for quick results) a 2 per cent solution of common salt.[1] Any one of these solutions is much denser than the cell-sap inside the cells of the pond-scum, and therefore the watery part of the cell-contents will be drawn out of the interior of the cell and the protoplasmic lining will collapse, receding from the cell-wall. The cell-contents are then said to be *plasmolyzed*. Sketch several cells in this condition. Remove the filaments of *Spirogyra* and place them in fresh water. How do they now behave? Explain. Repeat the plasmolyzing operation with another set of cells which have first been killed by soaking them for five minutes in a mixture of equal quantities of acetic acid, three parts to 1000 of water, and chromic acid, seven parts to 1000 of water. The pond-scum threads before being transferred from the killing solution into the plasmolyzing solution should be rinsed with a little clear water. Note how the cells now behave. How is it shown that they have lost their power of causing a liquid to be transferred mainly or wholly in one direction? Why do frozen or boiled slices of a red beet color water in which they are placed, while fresh slices do not?

65. Osmosis in Root-Hairs. — The soil-water (practically identical with ordinary spring or well water) is separated from the more or less sugary or mucilaginous sap inside of the root-hairs only by their delicate cell-walls, lined with a thin layer of protoplasm. This soil-water will pass rapidly into the plant, while very little of the sap will come out. The selective action, which causes the flow of liquid through the root-hairs to be almost wholly inward, is due to the living layer of protoplasm (Chapter XII), which covers the inner surface of the cell-wall of the root-hair. When the student has learned how active a substance protoplasm often shows itself to be, he will not be astonished to find it behaving almost as though it were

[1] This should be done as a demonstration by the teacher.

possessed of intelligence and will. Plants of two different species, both growing in the same soil, usually take from it very various amounts or kinds of mineral matter. For instance, barley plants in flower and red-clover plants in flower contain about the same proportion of mineral matter (left as ashes after burning). But the clover contains $5\frac{2}{3}$ times as much lime as the barley, and the latter contains about eighteen times as much silica as the clover. This difference must be due to the selective action of the protoplasm in the absorbing cells of the roots. Traveling by osmotic action from cell to cell, a current of water derived from the root-hairs is forced up through the roots and into the stem, just as the contents of the egg was forced up into the tube shown in Fig. 24.

66. Root-Pressure. — The force with which the upward-flowing current of water presses may be estimated by attaching a mercury gauge to the root of a tree or the stem of a small sapling. This is best done in early spring after the thawing of the ground, but before the leaves have appeared. The experiment may also be performed indoors upon almost any plant with a moderately firm stem, through which the water from the soil rises freely. A dahlia plant or a tomato plant answers well, though the root-pressure from one of these will not be nearly as great as that from a larger shrub or a tree growing out of doors. In Fig. 25 the apparatus is shown attached to the stem of a dahlia. The difference of level of the mercury in the bent tube serves to measure the root-pressure. For every foot of difference in level there must be a pressure of nearly six pounds per square inch on the stump at the base of the tube *T*.[1]

[1] See *Handbook*.

A black-birch root tested in this way at the end of April has given a root-pressure of thirty-seven pounds to the square inch. This would sustain a column of water about eighty-six feet high.

67. Root-Absorption and Temperature of Soil. — It would not be remarkable if the temperature of roots and the earth about them had something to do with the rate at which they absorb water, since this absorption depends on the living protoplasm of the root-hairs (see Sects. 64, 65). An experiment will serve to throw some light on this question.

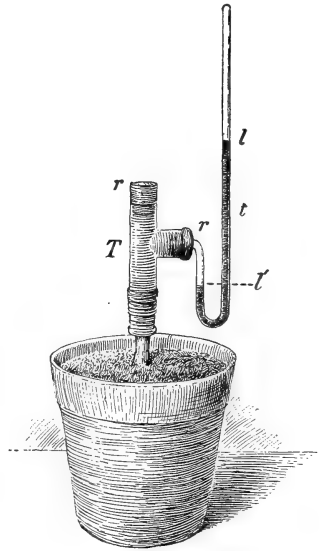


FIG. 25. — Apparatus to Measure Root-Pressure.

T, large tube fastened to the stump of the dahlia stem by a rubber tube; *rr*, rubber stoppers; *t*, bent tube containing mercury; *l l'*, upper and lower level of mercury in *T*.

EXPERIMENT XVII

Effect of Temperature on Absorption of Water by Roots. — Transplant a tobacco seedling about four inches high into rich earth contained in a narrow, tall beaker or very large test-tube (not less than $1\frac{1}{4}$ inch in diameter and six inches high). When the plant has begun to grow again freely, in a warm, sunny room, insert a chemical thermometer into the earth, best by making a hole with a sharp round stick, pushed nearly to the bottom of the tube, and then putting the thermometer in the place of the stick. Water the plant well, then set the tube in a jar of pounded ice which reaches nearly to the top of the tube. Note the temperature of the earth just before placing it in the ice. Observe whether the leaves of the seedling wilt,

and, if so, at what temperature the wilting begins. Finally, remove the tube from the ice and place it in warm water (about 80°). Observe the effect and note the temperature at which the plant, if wilted, begins to revive. Find an average between the wilting temperature and the reviving temperature. For what does this average stand?

68. Movements of Young Roots. — The fact that roots usually grow downward is so familiar that we do not generally think of it as a thing that needs discussion or explanation. Since they are pretty flexible, it may seem as though young and slender roots merely hung down by their own weight, like so many bits of wet cotton twine. But a very little experimenting will answer the question whether this is really the case.

EXPERIMENT XVIII

Do all Parts of the Root of the Windsor Bean Seedling bend downward alike? — Fasten some sprouting Windsor beans with roots about an inch in length to the edges of a disk of pine wood or other soft wood in a soup-plate nearly full of water and cover them with a low bell-jar. Pins run through the cotyledons, as in Fig. 26, will hold the beans in place. When the roots have begun to point downward strongly, turn most of the beans upside down and pin them in the reversed position. If you choose, after a few days reverse them again. Make sketches of the various forms that the roots assume and discuss these.

EXPERIMENT XIX

Does the Windsor Bean Root-Tip press downward with a Force greater than its Own Weight? — Arrange a sprouted bean as shown in Fig. 26, selecting one that has a root about twice as long as the diameter of the bean and that has grown out horizontally, having been sprouted on a sheet of wet blotting paper. The bean is pinned

to a cork that is fastened with beeswax and resin mixture to the side of a little trough or pan of glass or glazed earthenware. The pan is filled half an inch or more with mercury, and on top of the mercury is a layer of water. The whole is closely covered by a large tumbler or a bell-glass. Allow the apparatus to stand until the root has forced its way down into the mercury. Then run a slender needle into the root where it enters the mercury (to mark the exact level), withdraw the root, and measure the length of the part submerged in mercury. To see whether this part would have stayed under by virtue of its own weight, cut it off and lay it on the mercury. Push it under with a pair of steel forceps and then let go of it. What does it do?

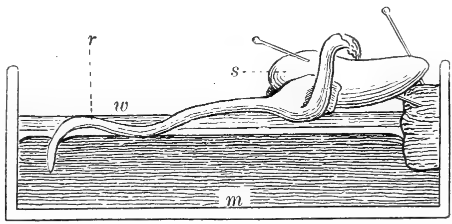


FIG. 26. — A Sprouting Windsor Bean pushing its Root-Tip into Mercury.

s, seed; *r*, root; *w*, layer of water; *m*, mercury.

69. Discussion of Exp. XIX. — By comparing the weights of equal bulks of mercury and Windsor bean roots, it is found that the mercury is about fourteen times as heavy as the substance of the roots. Evidently, then, the submerged part of the root must have been held under by a force about fourteen times its own weight. Making fine equidistant cross-marks with ink along the upper and the lower surface of a root that is about to bend downward at the tip, readily shows that those of the upper series soon come to be farther apart, — in other words, that *the root is forced to bend downward by the more rapid growth of its upper as compared with its under surface.*

70. Geotropism. — The property which plants or their organs manifest, of assuming a definite direction with

reference to gravity,[1] is called *geotropism.* When, as in the case of the primary root, the effect of gravity is to make the part if unobstructed turn or move downward, we say that the geotropism is *positive.* If the tendency is to produce upward movement, we say that the geotropism is *negative;* if horizontal movement, that it is *lateral.* It was stated in the preceding section that the direct cause of the downward extension of roots is unequal growth. We might easily suppose that this unequal growth is not due to gravity, but to some other cause. To test this supposition, the simplest plan (if it could be carried out) would be to remove the plants studied to some distant region where gravity does not exist. This of course cannot be done, but we can easily turn a young seedling over and over so that gravity will act on it now in one direction, now in another, and so leave no more impression than if it did not act at all (Exp. XX). Or we can whirl a plant so fast that not only is gravity done away with, but another force is introduced in its place. If a vertical wheel, like a carriage wheel, were provided with a few loosely fitting iron rings strung on the spokes, when the wheel was revolved rapidly the rings would all fly out to the rim of the wheel. So in Fig. 27 it will be

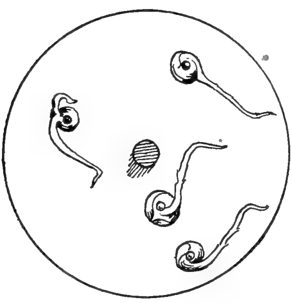


FIG. 27.—Sprouting Peas, on the Disk of a rapidly Whirling Clinostat.

The youngest portions of the roots all point directly away from the axis about which they were revolved.

[1] Gravity means the pull which the earth exerts upon all objects on or near its surface.

noticed that the growing tips of the roots of the sprouting peas point almost directly outward from the center of the disk on which the seedlings are fastened. Explain the difference between this result and that obtained in Exp. XX.

EXPERIMENT XX

How do Primary Roots point when uninfluenced by Gravity? Pin some soaked Windsor beans to a large flat cork, cover them with thoroughly moistened chopped peat-moss, and cover this with a thin glass crystallizing dish. Set the cork on edge. Prepare another cork in the same way, attach it to a clinostat, and keep it slowly revolving in a vertical position for from three to five days. Compare the directions taken by the roots on the stationary and on the revolving cork.[1]

71. Direction taken by Secondary Roots. — As the student has already noticed in the seedlings which he has studied, the branches of the primary root usually make a considerable angle with it (Fig. 2). Often they run out for long distances almost horizontally. This is especially common in the roots of forest trees, above all in cone-bearing trees, such as pines and hemlocks. This horizontal or nearly horizontal position of large secondary roots is the most advantageous arrangement to make them useful in staying or guying the stem above, to prevent it from being blown over by the wind.

72. Fitness of the Root for its Position and Work. — The distribution of material in the woody roots of trees and shrubs and their behavior in the soil show many adaptations to the conditions by which the roots are surrounded.

[1] See Ganong's *Teaching Botanist*, pp. 182–186, for complete directions. The brief statement above given is abstracted from that of Professor Ganong.

The growing tip of the root, as it pushes its way through the soil, is exposed to bruises; but these are largely warded off by the root-cap. The tip also shows a remarkable sensitiveness to contact with hard objects, so that when touched by one it swerves aside and thus finds its way downward by the easiest path. Roots with an unequal water supply on either side grow toward the moister soil. Roots are very tough, because they need to resist strong

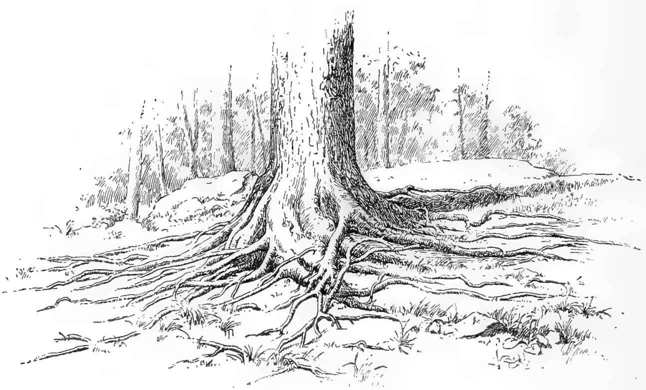


FIG. 28.—Roots of a Western Hemlock exposed by having most of the Leaf-Mould about them burned away by Forest Fires.

pulls, but not as stiff as stems and branches of the same size, because they do not need to withstand sidewise pressure, acting from one side only. The corky layer which covers the outsides of roots is remarkable for its power of preventing evaporation. It must be of use in retaining in the root the moisture which otherwise might be lost on its way from the deeper rootlets (which are buried in damp soil), through the upper portions of the root-system, about which the soil is often very dry.

73. Propagation by Means of Roots. — Some familiar plants, such as rose bushes, are usually grown from roots or root-cuttings.

Bury a sweet potato or a dahlia root in damp sand, and watch the development of sprouts from adventitious buds. One sweet potato will produce several such crops of sprouts, and every sprout may be made to grow into a new plant. It is in this way that the crop is started wherever the sweet potato is grown for the market.

74. Tabular Review of Experiments.

[Continue the table begun at end of Chapter III.]

75. Review Summary of Roots.

Kinds of roots as regards origin	
Kinds as regards medium in which they grow .	
Structure of root of a tree.	
Storage in roots	materials. location. uses.
Absorption of water by roots	apparatus. amount. proofs. causes.
Movements of roots	nature. causes. uses.

CHAPTER V

STEMS

76. What the Stem is. — The work of taking in the raw materials which the plant makes into its own food is done mainly by the roots and the leaves. These raw materials are taken from earth, from water, and from the air (see Chapter XI). The stem is that part or organ of the plant which serves to bring roots and leaves into communication with each other. In most flowering plants the stem also serves the important purpose of lifting the leaves up into the sunlight, where alone they best can do their special work.

The student has already, in Chapter III, learned something of the development of the stem and the seedling; he has now to study the external appearance and internal structure of the mature stem. Much in regard to this structure can conveniently be learned from the examination of twigs and branches of our common forest trees in their winter condition.

77. The Horse-Chestnut Twig.[1] — Procure a twig of horse-chestnut eighteen inches or more in length. Make a careful sketch of it, trying to bring out the following points:

(1) The general character of the bark.

[1] Where the buckeye is more readily obtained it will do very well. Hickory twigs answer the same purpose, and the latter is a more typical form, having alternate buds. The magnolia or the tulip tree will do. The student should (sooner or later) examine at least one opposite- and one alternate-leaved twig.

(2) The large horseshoe-shaped scars and the number and position of the dots on these scars. Compare a scar with the base of a leaf-stalk furnished by the teacher.

(3) The ring of narrow scars around the stem in one or more places,[1] and the different appearance of the bark above and below such a ring. Compare these scars with those left after removing the scales of a terminal bud and then see Fig. 29, *b sc*.

(4) The buds at the upper margin of each leaf-scar and the strong terminal bud at the end of the twig.

(5) The flower-bud scar, a concave impression, to be found in the angle produced by the forking of two twigs, which form, with the branch from which they spring, a Y-shaped figure (see Fig. 36).

(6) (On a branch larger than the twig handed round for individual study) the place of origin of the twigs on the branch; — make a separate sketch of this.

FIG. 29. — A quickly grown Twig of Cherry, with Lateral and Terminal Buds in October.

b sc, bud-scale scars. All above these scars is the growth of the spring and summer of the same year.

The portion of stem which originally bore any pair of leaves is called a *node*, and the portions of stem between nodes are called *internodes*.

Describe briefly in writing alongside the sketches any observed facts which the drawings do not show.

If your twig was a crooked, rough-barked, and slow-growing one, exchange it for a smooth, vigorous one, and note the differences. Or if you sketched a quickly grown shoot, exchange for one of the other kind.

Answer the following questions:

(*a*) How many inches did your twig grow during the last summer?

How many in the summer before?

How do you know?

How many years old is the whole twig given you?

(*b*) How were the leaves arranged on the twig?

[1] A very vigorous shoot may not show any such ring.

How many leaves were there?

Were they all of the same size?

(*c*) What has the mode of branching to do with the arrangement of the leaves? with the flower-bud scars?

(*d*) The dots on the leaf-scars mark the position of the bundles of ducts and wood-cells which run from the wood of the branch through the leaf-stalk up into the leaf.

78. Twig of Beech. — Sketch a vigorous young twig of beech (or of hickory, magnolia, tulip tree) in its winter condition, noting particularly the respects in which it differs from the horse-chestnut. Describe in writing any facts not shown in the sketch. Notice that the buds are not opposite, nor is the next one above any given bud found directly above it, but part way round the stem from the position of the first one. Ascertain, by studying several twigs and counting around, which bud is above the first and how many turns round the stem are made in passing from the first to the one directly above it.

Observe with especial care the difference between the beech and the horse-chestnut in mode of branching, as shown in a large branch provided for the study of this feature.

79. Relation of Leaf-Arrangement to Branching.[1] — This difference, referred to in Sect. 78, depends on the fact that the leaves of the horse-chestnut were arranged in pairs, on opposite sides of the stem, while those of the beech were not in pairs. Since the buds are found at the upper edges of the leaf-scars, and since most of the buds of the horse-chestnut and the beech are leaf-buds and destined to form branches, the mode of branching and ultimately the form

[1] The teacher in the Eastern and Middle States will do well to make constant use, in the study of branches and buds, of Miss Newell's *Outlines of Lessons in Botany*, Part I. The student can observe for himself, with a little guidance from the teacher, most of the points which Miss Newell suggests. If the supply of material is abundant, the twigs employed in the lessons above described need not be used further, but if material is scanty, the study of buds may at once be taken up. (See also Bailey's *Lessons with Plants*, Part I.)

of the tree must depend largely on the arrangement of leaves along the stem.

80. Opposite Branching. — In trees the leaves and buds of which are opposite, the tendency will be to form twigs in four rows about at right angles to each other along the sides of the branch, as shown in Fig. 30.

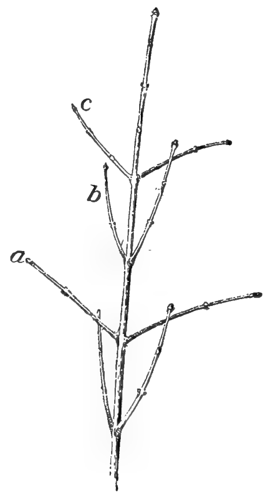


FIG. 30. — Opposite Branching in a very Young Sapling of Ash.

This arrangement will not usually be perfectly carried out, since some of the buds may never grow, or some may grow much faster than others and so make the plan of branching less evident than it would be if all grew alike.

FIG. 31. — Alternate Branching in a very Young Apple Tree.

81. Alternate Branching. —In trees like the beech the twigs will be found to be arranged in a more or less regular spiral line about the branch. This, which is known as the *alternate* arrangement (Fig. 31), is more commonly met with in trees and shrubs than the *opposite* arrangement. It admits of many varieties, since the spiral may wind more or less rapidly round the stem. In the apple, pear, cherry, poplar, oak, and walnut, one passes

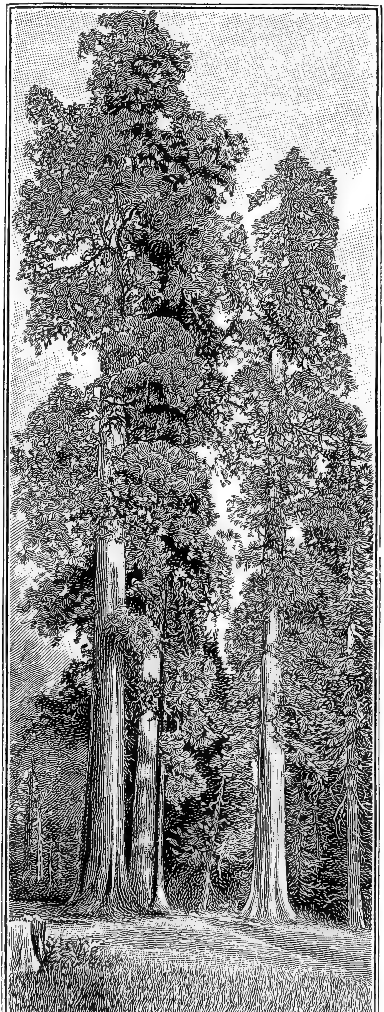


FIG. 32. — Excurrent Trunks of Big Trees (*Sequoias*).

over five spaces before coming to a leaf which is over the first, and in doing this it is necessary to make two complete turns round the stem (Fig. 105).

82. Growth of the Terminal Bud. — In some trees the terminal bud from the very outset keeps the leading place, and the result of this mode of growth is to produce a slender, upright tree, with an *excurrent* trunk like that of Fig. 32.

In such trees as the apple and many oaks the terminal bud has no preeminence over others, and the form of the tree is round-topped and spreading, *deliquescent* like that in Fig. 33.

Most of the larger forest trees are intermediate between these extremes.

Branches get their characteristics to a

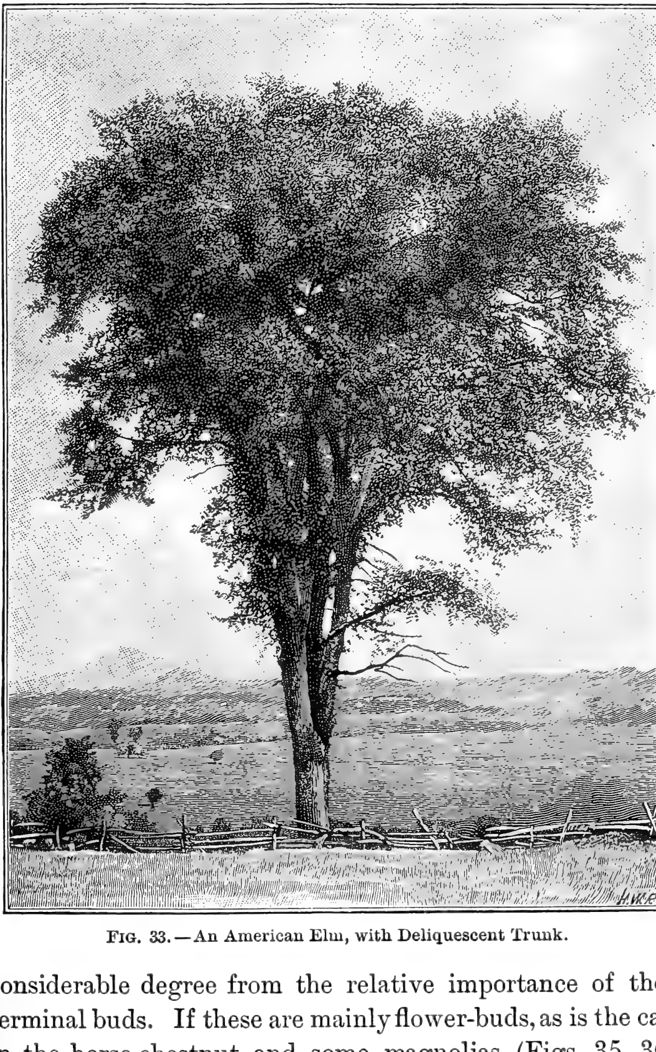


FIG. 33.—An American Elm, with Deliquescent Trunk.

considerable degree from the relative importance of their terminal buds. If these are mainly flower-buds, as is the case in the horse-chestnut and some magnolias (Figs. 35, 36),

the tree is characterized by frequent forking, and has no long horizontal branches.

If the terminal bud keeps the lead of the lateral ones, but the latter are numerous and most of them grow into slender twigs, the delicate spray of the elm and many birches is produced (Fig. 37).

The general effect of the branching depends much upon the angle which each branch or twig forms with that one from which it springs. The angle may be quite acute, as in the birch; or more nearly a right angle, as in the ash (Fig. 30). The inclination of lateral branches is due to geotropism, just as is that of the branches of primary roots. The vertically upward direction of the shoot which grows from the terminal bud is also due to geotropism.

This is really only a brief way of saying that the growing tip of the main stem of the tree or of any branch is made to take and keep its proper direction, whether vertically upward or at whatever angle is desirable for the tree, by the steering action of gravity. After growth has ceased this steering action can no longer be exerted, and so a tree that has been bent over (as, for instance, by a heavy load of snow) cannot right itself, unless it is elastic enough to spring back when the load is removed. The tip of the trunk and of each branch can grow and thus become vertical, but the old wood cannot do so.

83. Thorns as Branches. — In many trees some branches show a tendency to remain dwarfish and incompletely developed. Such imperfect branches forming thorns are familiar in wild crab-apple trees and in the pear trees which occur in old pastures in the Northeastern States. In the honey locust very formidable branching spines spring

from adventitious or dormant buds on the trunk or limbs. Such spines sometimes show their true nature as branches by bearing leaves (Fig. 34).

84. Indefinite Annual Growth. — In most of the forest trees, and in the larger shrubs, the wood of young branches is matured and fully developed during the summer. Protected buds are formed on the twigs of these branches to their very tips. In other shrubs — for example, in the sumac, the raspberry, and blackberry — the shoots continue to grow until their soft and immature tips are killed by the frost. Such a mode of growth is called *indefinite annual growth*, to distinguish it from the *definite annual growth* of most trees.

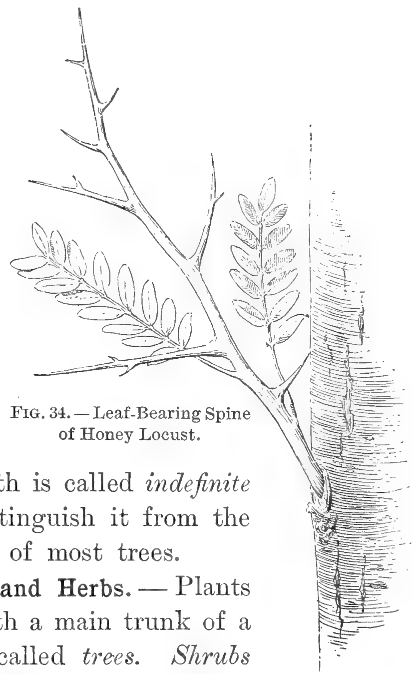


FIG. 34. — Leaf-Bearing Spine of Honey Locust.

85. Trees, Shrubs, and Herbs. — Plants of the largest size with a main trunk of a woody structure are called *trees*. *Shrubs* differ from trees in their smaller size, and generally in having several stems which proceed from the ground or near it or in having much-forked stems. The witch-hazel, the dogwoods, and the alders, for instance, are most of them classed as shrubs for this reason, though in height some of them equal the smaller trees. Some of

the smallest shrubby plants, like the dwarf blueberry, the wintergreen, and the trailing arbutus, are only a few inches

FIG. 35. — Tip of a Branch of Magnolia, illustrating Forking due to Terminal Flower-Buds.

A, oldest flower-bud scar; *B*, *C*, *D*, scars of successive seasons after *A*; *L*, leaf-buds; *F*, flower-buds.

in height, but are ranked as shrubs because their woody stems do not die quite to the ground in winter.

Herbs are plants whose stems above ground die every winter.

86. Annual, Biennial, and Perennial Plants. — *Annual* plants are those which live but one year, *biennials* those which live two years or nearly so.

Some annual plants may be made to live over winter, flowering in their second summer. This is true of winter wheat and rye among cultivated plants.

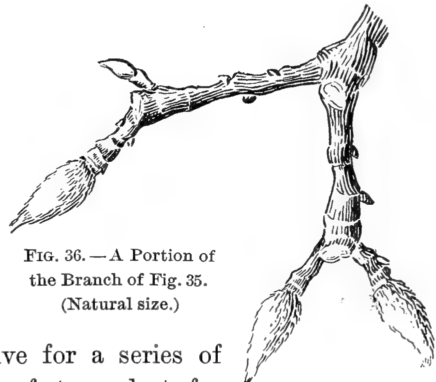


FIG. 36. — A Portion of the Branch of Fig. 35. (Natural size.)

Perennial plants live for a series of years. Many kinds of trees last for centuries. The Californian giant redwoods, or *Sequoias* (Fig. 32), which reach a height of over 300 feet under favorable circumstances, live nearly 2000 years; and some

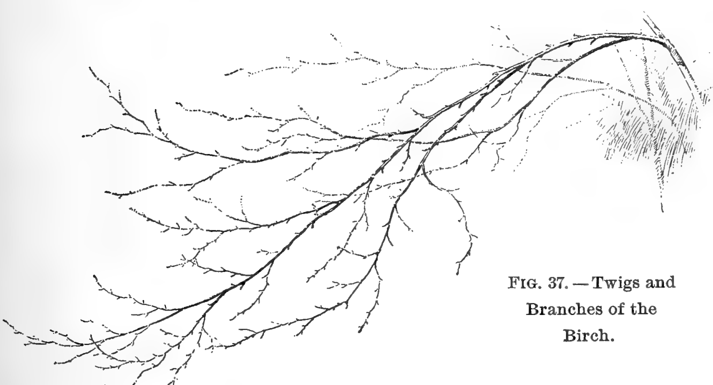


FIG. 37. — Twigs and Branches of the Birch.

monstrous cypress trees found in Mexico were thought by Professor Asa Gray to be from 4000 to 5000 years old.

87. Stemless Plants. — As will be shown later (Chapter XXX), plants live subject to a very fierce competition among themselves and exposed to almost constant attacks from animals.

While plants with long stems find it to their advantage to reach up as far as possible into the sunlight, the cinquefoil, the white clover, the dandelion, some spurges, the knotgrass, and hundreds of other kinds of plants have found safety in hugging the ground.

FIG. 38. — The Dandelion ; a so-called Stemless Plant.

Any plant which can grow in safety under the very feet of grazing animals will be especially likely to make its way in the world, since there are many places where it can flourish while ordinary plants would be destroyed. The bitter, stemless dandelion, which is almost uneatable for most animals, unless cooked, which lies too near the earth to be fed upon by grazing animals, and which bears being trodden on with impunity, is a type of a large class of hardy weeds.

The so-called *stemless plants*, like the dandelion (Fig. 38), and some violets, are not really stemless at all, but send

out their leaves and flowers from a very short stem, which hardly rises above the surface of the ground.

88. Climbing and Twining Stems.[1] — Since it is essential to the health and rapid growth of most plants that they should have free access to the sun and air, it is not strange that many should resort to special devices for lifting themselves above their neighbors. In tropical forests, where the darkness of the shade anywhere beneath the tree-tops is so great that few flowering plants can thrive in it, the climbing plants or *lianas* often run like great cables for hundreds of feet before they can emerge into the sunshine above. In temperate climates no such remarkable climbers are found, but many plants raise themselves for considerable distances. The principal means to which they resort for this purpose are:

FIG. 39. — Lianas strangling a Palm.

(1) Producing roots at many points along the stem above ground and climbing on suitable objects by means of these, as in the English ivy (Fig. 15).

(2) Laying hold of objects by means of tendrils or *twining branches* or *leaf-stalks*, as shown in Figs. 40, 41.

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. I, p. 669.

(3) Twining about any slender upright support, as shown in Fig. 42.

89. Tendril-Climbers. — The plants which climb by means of tendrils are important subjects for study, but they cannot usually be managed very well in the schoolroom. Continued observation soon shows that the tips of tendrils sweep slowly about in the air until they come in contact with some object about which they can coil themselves. After the tendril has taken a few turns about its support, the free part of the tendril coils into a spiral and thus draws the whole stem toward the point of attachment, as shown in Fig. 40. Some tendrils are modified leaves or stipules, as shown in Fig. 104; others are modified stems.

FIG 40. — Coiling of a Tendril of Bryony.

90. Twiners. — Only a few of the upper internodes of the stem of a twiner are concerned in producing the movements of the tip of the stem. This is kept revolving in an elliptical or circular path until it encounters some roughish and not too stout object, about which it then proceeds to coil itself.

The movements of the younger internodes of the stems of twiners are among the most extensive of all the movements made by plants. A hop-vine which has climbed to the top of its stake may sweep its tip continually around the circumference of a circle two feet in diameter, and the

common wax-plant of the greenhouses sometimes describes a five-foot circle, the tip moving at the rate of thirty-two inches per hour.[1] This circular motion results from some cause not yet fully understood by botanists.[2]

The direction in which twiners coil about a supporting object is almost always the same for each species of plant, but not the same for all species. In the hop it is as

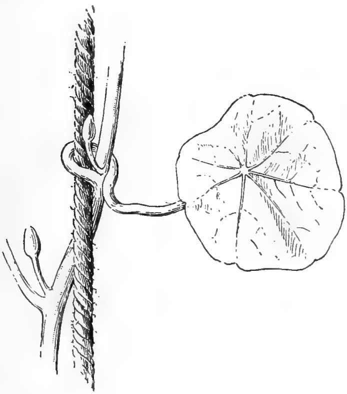


FIG. 41. — Coiling of Petiole of Dwarf Tropæolum.

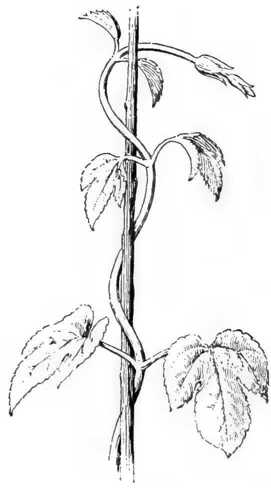


FIG. 42. — Twining Stem of Hop.

shown in Fig. 42. Is it the same as in the bean? in the morning-glory?

91. Underground Stems. — Stems which lie mainly or wholly underground are of frequent occurrence and of many kinds.

In the simplest form of *rootstock* (Fig. 43), such as is

[1] See article on *Climbing Plants*, by Dr. W. J. Beal, in the *American Naturalist*, Vol. IV, pp. 405–415.

[2] See Strasburger, Noll, Schenk, and Schimper, *Text-Book*, pp. 258–262; also Vines, *Students' Text-Book of Botany*, London and New York, 1894, pp. 759, 760.

found in some mints and in many grasses and sedges, the real nature of the creeping underground stem is shown by the presence upon its surface of many scales, which are reduced leaves. Rootstocks of this sort often extend horizontally for long distances in the case of grasses like the sea rye grass (Plate I), which roots itself firmly and thrives in shifting sand-dunes. In the stouter rootstocks, like that of the iris (Fig. 44) and the Caladium (Fig. 45), this stem-like character is less evident. The potato is an excellent example of the short and much-thickened underground stem known as a *tuber*.

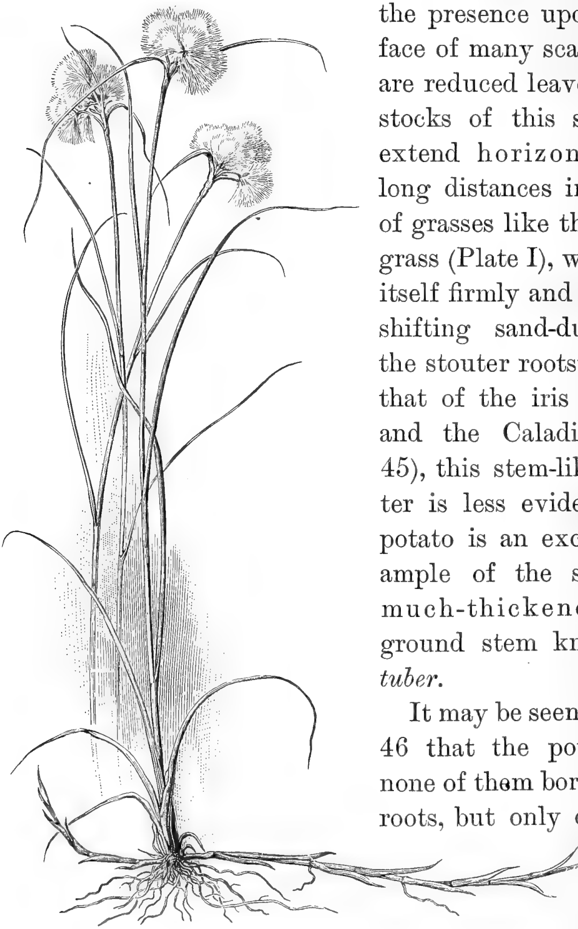


FIG. 43.—Rootstock of Cotton-Grass (*Eriophorum*).

It may be seen from Fig. 46 that the potatoes are none of them borne on true roots, but only on subterranean branches, which are stouter and more cylindrical than most of the roots. The "eyes"

Plate I. — A Sand-Loving Plant, Sea Rye Grass

FIG. 44.—Roots, Rootstocks, and Leaves of Iris.

which they bear are rudimentary leaves and buds.

Bulbs, whether coated like those of the onion or the hyacinth (Fig. 47), or scaly like those of the lily, are merely very short and stout underground stems, covered with closely crowded scales or layers which represent leaves or the bases of leaves (Fig. 48).

The variously modified forms of underground stems just discussed, illustrate in a marked way the storage of nourishment during the winter (or the rainless season, as the case may be) to secure rapid growth during the active season. It is interesting to notice that nearly all of the early-flowering herbs in temperate climates, like the crocus, the snowdrop, the spring-beauty, the

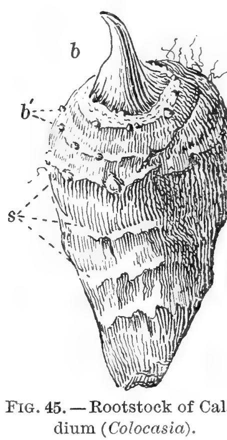


FIG. 45.—Rootstock of Caladium (*Colocasia*).

b, terminal bud; *b′*, buds arranged in circles where bases of leaves were attached; *s*, scars left by sheathing bases of leaves.

tulip, and the skunk-cabbage, owe their early-blooming habit to richly stored underground stems of some kind, or to thick, fleshy roots.

92. Condensed Stems. — The plants of desert regions require, above all, protection from the extreme dryness of the surrounding air, and, usually, from the excessive heat of the sun. Accordingly, many desert plants are found quite destitute of ordinary foliage, exposing to the air only a small surface. In the melon-cactuses (Fig. 49) the stem appears reduced to the shape in which the least possible surface is presented by a plant of given bulk, — that is, in a globular form. Other cactuses are more or less cylindrical or prismatic, while still others consist of flattened joints; but all agree in offering much less area to the sun and air than is exposed by an ordinary leafy plant.

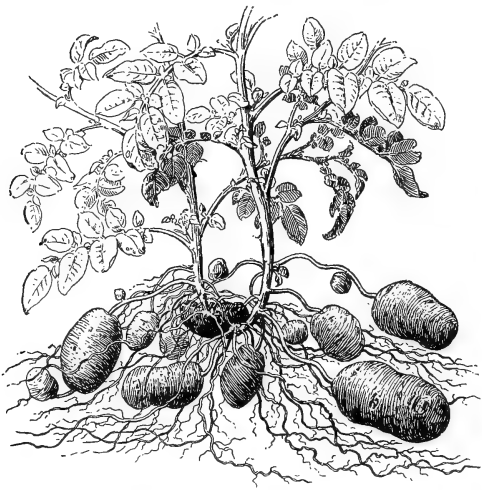


FIG. 46. — Part of a Potato Plant.
The dark tuber in the middle is the one from which the plant has grown.

93. Leaf-Like Stems.—The flattened stems of some kinds of cactus (especially the common, showy *Phyllocactus*) are sufficiently like fleshy leaves, with their dark green color and imitation of a midrib, to pass for leaves. There are,

however, a good many cases in which the stem takes on a more strikingly leaf-like form. The common asparagus sends up in spring shoots that bear large scales which are really reduced leaves. Later in the season, what seem like thread-like leaves cover the much-branched mature plant, but these green threads are actually minute branches, which perform the work of leaves (Fig. 50). The familiar greenhouse climber, wrongly known as smilax (properly called *Myrsiphyllum*), bears a profusion of what appear to be delicate green leaves (Fig. 51). Close study, however, shows that these are really short, flattened branches, and that each little branch springs from the axil of a true leaf, *l*, in the form of a minute scale. Sometimes a flower and a leaf-like branch spring from the axil of the same scale.

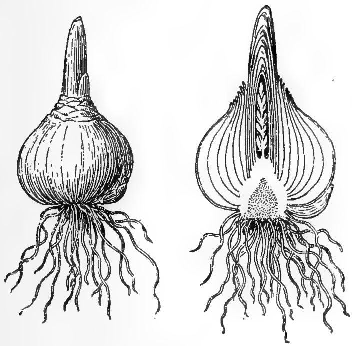


FIG. 47.—Bulb of Hyacinth. (Exterior view and split lengthwise.)

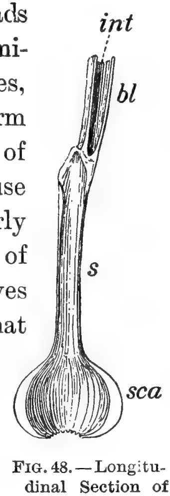


FIG. 48.—Longitudinal Section of an Onion Leaf.

sca, thickened base of leaf, forming a bulb-scale; *s*, thin sheath of leaf; *bl*, blade of the leaf; *int*, hollow interior of blade.

Branches which, like those of *Myrsiphyllum*, so closely resemble leaves as to be almost indistinguishable from them are called *cladophylls*.

94. Modifiability of the Stem.—The stem may, as in the tallest trees, in the great lianas of South American forests,

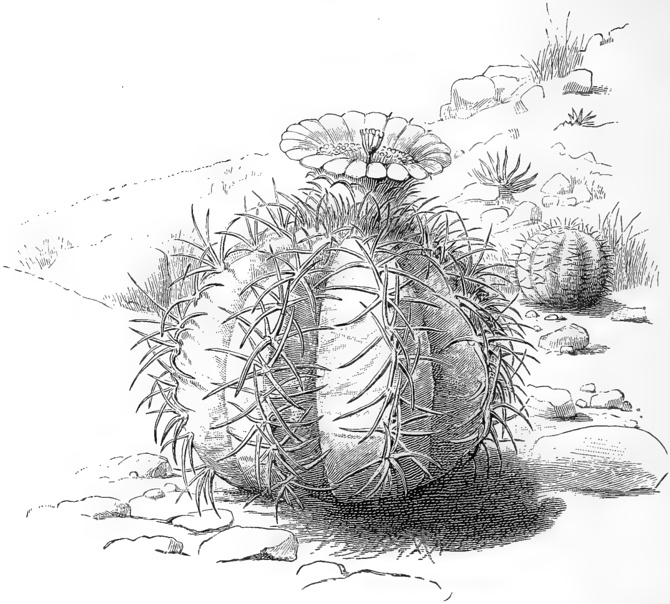


FIG. 49. — A Melon-Cactus.

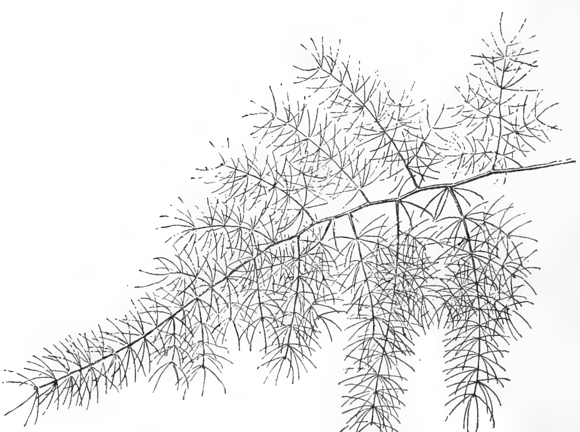


FIG. 50. — A Spray of a Common Asparagus (not the edible species).

or the rattan of Indian jungles, reach a length of many hundred feet. On the other hand, in such "stemless" plants as the primrose and the dandelion, the stem may be reduced to a fraction of an inch in length. It may take

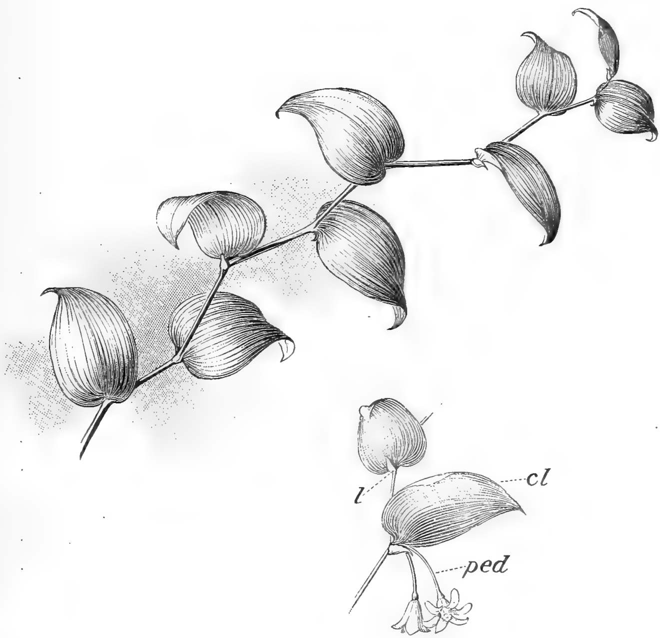


FIG. 51.—Stem of "Smilax" (*Myrsiphyllum*).
l, scale-like leaves; *cl*, cladophyll, or leaf-like branch, growing in the axil of the leaf; *ped*, flower-stalk, growing in the axil of a leaf.

on apparently root-like forms, as in many grasses and sedges, or become thickened by underground deposits of starch and other plant-food, as in the iris, the potato, and the crocus. Condensed forms of stem may exist above ground, or, on the other hand, branches may be flat and

thin enough closely to imitate leaves. In short, the stem manifests great readiness in adapting itself to the most varied conditions of existence.

95. Review Summary of Stems.[1]

Kinds of branching due to leaf arrangement	1. 2.
Kinds of tree-trunk due to greater or less predominance of terminal bud	1 2.
Classes of plants based on amount of woody stem . .	1. 2. 3.
Classes of plants based on duration of life	1. 2. 3.
Various modes of climbing	1. 2. 3.
Kinds of underground stem	1. 2. 3.
Condensed stems above ground	
Leaf-like stems	

[1] Where it is possible to do so, make sketches; where this is not possible, give examples of plants to illustrate the various kinds or classes of plants in the summary.

CHAPTER VI

STRUCTURE OF THE STEM

STEM OF MONOCOTYLEDONOUS PLANTS

96. Gross Structure. — Refer back to the sketches of the corn seedling, to recall something of the early history of the corn-stem. Study the external appearance of a piece of corn-stem or bamboo two feet or more in length. Note the character of the outer surface. Sketch the whole piece and label the enlarged *nodes* and the nearly cylindrical *internodes*. Cut across a corn-stem and examine the cut surface with the magnifying glass. Make some sections as thin as they can be cut and examine with the magnifying glass (holding them up to the light) or with a dissecting microscope. Note the firm rind, composed of the epidermis and underlying tissue, the large mass of pith composing the main bulk of the stem, and the many little harder and more opaque spots, which are the cut-off ends of the woody threads known as *fibro-vascular bundles* (Fig. 52).

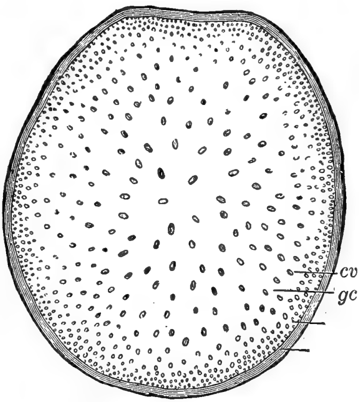


FIG. 52. — Diagrammatic Cross-Section of Stem of Indian Corn.
cv, fibro-vascular bundles; *gc*, pithy material between bundles.

Split a portion of the stem lengthwise into thin translucent slices and notice whether the bundles seem to run straight up and down its length; sketch the entire section × 2. Every fibro-vascular bundle of the stem passes outward through some node in order to connect with some fibro-vascular

bundle of a leaf. This fact being known to the student would lead him to expect to find the bundles bending out of a vertical position more at the nodes than elsewhere. Can this be seen in the stem examined?

Observe the enlargement and thickening at the nodes, and split one of these lengthwise to show the tissue within it.

Compare with the corn-stem a piece of palmetto and a piece of cat-brier (*Smilax rotundifolia*, *S. hispida*, etc.), and notice the similarity of structure, except for the fact that the tissue in the palmetto and the cat-brier which answers to the pith of the corn-stem is much darker colored and harder than corn-stem pith. Compare also a piece of rattan and of bamboo.

97. Minute Structure. — Cut a thin cross-section of the corn-stem, examine with a low power of the microscope, and note:

(*a*) The rind (not true bark), composed largely of hard, thick-walled dead cells, known as *sclerenchyma* fibers.

(*b*) The fibro-vascular bundles. Where are they most abundant? least abundant?

(*c*) The pith, occupying the intervals between the fibro-vascular bundles.

Study the bundles in various portions of the section and notice particularly whether some are more porous than others. Explain. Sketch some of the outer and some of the inner ones.

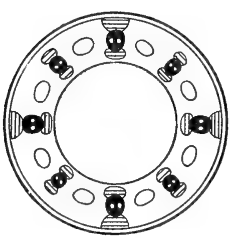


FIG. 53. — Diagrammatic Cross-Section of Stem of Bulrush (*Scirpus*), a Hollow Cylinder with Strengthening Fibers.

A more complicated kind of monocotyledonous stem-structure can be studied to advantage in the surgeons' splints cut from yucca-stems and sold by dealers in surgical supplies.

98. Mechanical Function of the Manner of Distribution of Material in Monocotyledonous Stems. — The well-known strength and lightness of the straw of our smaller grains and of rods of cane or bamboo are due to their form. It can readily be shown

by experiment that an iron or steel tube of moderate thickness, like a piece of gas-pipe, or of bicycle-tubing, is much stiffer than a solid rod of the same weight per foot. The oat straw, the stems of bulrushes (Fig. 53), the cane (of our southern canebrakes), and the bamboo are hollow cylinders; the cornstalk is a solid cylinder, but filled with a very light pith. The flinty outer layer of the stalk, together with the closely packed sclerenchyma fibers of the outer rind and the frequent fibro-vascular bundles just within this, are arranged in the best way to secure stiffness. In a general way, then, we may say that the pith, the bundles, and the sclerenchymatous rind are what they are and where they are to serve important mechanical purposes. But they have other uses fully as important (Fig. 78).

FIG. 54. — Group of Date-Palms.

99. Growth of Monocotyledonous Stems in Thickness. — In most woody monocotyledonous stems, for a reason

which will be explained later in this chapter, the increase in thickness is strictly limited. Such stems, therefore, as in many palms (Fig. 54) and in rattans, are less conical and more cylindrical than the trunks of ordinary trees and are also more slender in proportion to their height.

STEM OF DICOTYLEDONOUS PLANTS

100. Gross Structure of an Annual Dicotyledonous Stem. — Study the external appearance of a piece of sunflower-stem several inches long. If it shows distinct nodes, sketch it. Examine the cross-section and sketch it as seen with the magnifying glass or the dissecting microscope. *After your sketch is finished*, compare it with Fig. 55, which probably shows more details than your drawing, and label the parts shown as they are labeled in that figure. Split a short piece of the stem lengthwise through the center and study the split surface with the magnifying glass. Take a sharp knife or a scalpel and carefully slice and then scrape away the bark until you come to the outer surface of a bundle.

Examine a vegetable sponge (*Luffa*), sold by druggists, and notice that it is simply a network of fibro-vascular bundles. It is the skeleton of a tropical seed-vessel or fruit, very much like that of the wild cucumber, common in the Central States, but a great deal larger.

The different layers of the bark cannot all be well recognized in the examination of a single kind of stem. Examine (*a*) the *cork* which constitutes the outer layers of the bark of cherry or birch branches two or more years old. Sketch the roundish or oval spongy *lenticels* on the outer surface of the bark. How far in do they extend? Examine (*b*) the *green layer* of bark as shown in twigs or branches of Forsythia, cherry, alder, box-elder, wahoo, or willow. Examine (*c*) the white, fibrous inner layer, known as *hard bast*, of the bark of elm, leatherwood, pawpaw, or basswood.

101. Minute Structure of the Dicotyledonous Stem. — Study, first with a low and then with a medium power of the compound microscope, thin cross-sections of clematis-stem cut just before the end of

the first season's growth.[1] Sketch the whole section without much detail, and then make a detailed drawing of a sector running from center to circumference and just wide enough to include one of the large bundles. Label these drawings in general like Figs. 55, 56.

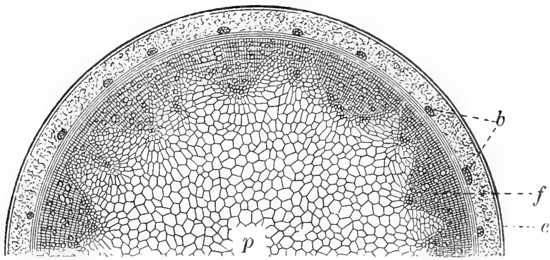


FIG. 55. — Diagrammatic Cross-Section of an Annual Dicotyledonous Stem. (Somewhat magnified.)

p, pith; *fv*, woody or fibro-vascular bundles; *e*, epidermis; *b*, bundles of hard bast fibers of the bark.

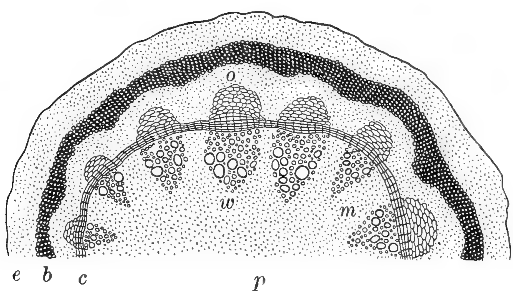


FIG. 56. — Diagrammatic Cross-Section of One-Year-Old *Aristolochia* Stem. (Considerably magnified.)

e, region of epidermis; *b*, hard bast; *o*, outer or bark part of a bundle (the cellular portion under the letter); *w*, inner or woody part of bundle; *c*, cambium layer; *p*, region of pith; *m*, a medullary ray.

The space between the hard bast and the bundles is occupied by thin-walled, somewhat cubical cells of the bark.

[1] *Clematis virginiana* is simpler in structure than some of the other woody species. *Aristolochia* sections will do very well.

Note:

(a) The general outline of the section.

(b) The number and arrangement of the bundles. (How many kinds of bundles are there?)

(c) The comparative areas occupied by the woody part of the bundle and by the part which belongs to the bark.

(d) The way in which the pith and the outer bark are connected (and the bundles separated) by the *medullary rays*.

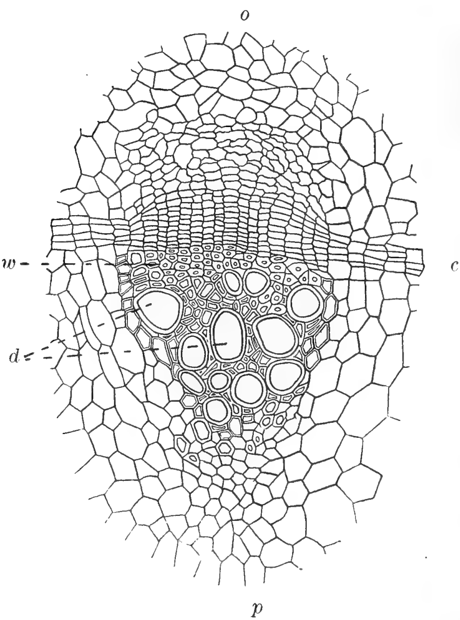


FIG. 57.—One Bundle from the Preceding Figure. (× 100.)
w, wood-cells; *d*, ducts. The other letters are as in Fig. 56. Many sieve-cells occur in the region just outside of the cambium of the bundle.

Examine a longitudinal section of the same kind of stem, to find out more accurately of what kinds of cells the pith, the bundles, and the outer bark are built. Which portion has cells that are nearly equal in shape, as seen in both sections?

102. Mechanical Importance of Distribution of Material in the Dicotyledonous Stem. — It is easy to see that those tissues which are tough, like hard bast, and those which are both tough and stiff, like wood fibers, are arranged in a tubular fashion in young dicotyledonous stems as they are in some monocotyledonous ones (Fig. 53). Sometimes the interior of the stem is quite hollow, as, for example,

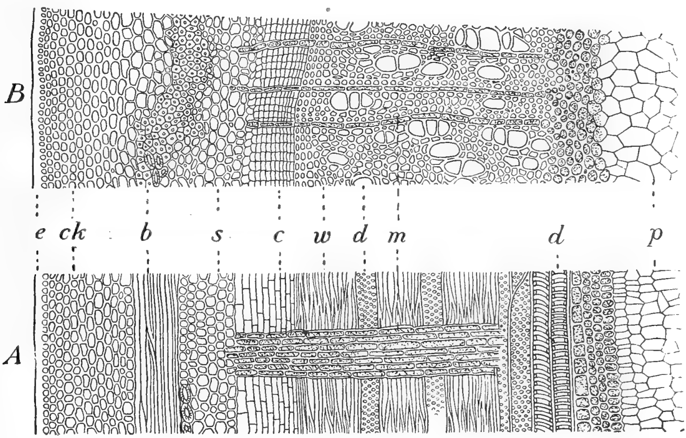


FIG. 58. — Stem of Box-Elder One Year Old. (Much magnified.)

A, lengthwise (radial) section; *B*, cross-section; *e*, epidermis; *ck*, cork; *b*, hard bast; *s*, sieve-cells; *c*, cambium; *w*, wood-cells; *m*, medullary rays; *d*, ducts; *p*, pith.

in the stems of balsams, melons, cucumbers, and squashes, and in the flower-stalks of the dandelion. In older stems, such as the trunks of trees, the wood forms a pretty nearly solid cylinder.

Stiffness in dicotyledonous stems is secured mainly in two ways: (1) by hard bast fibers, (2) by wood fibers. Which of these types does the stem (Fig. 55) represent? Which does the flax-stem (Fig. 60) represent?

Notice that in both types bast fibers and wood fibers are present, but the proportions in (1) and (2) vary greatly.

103. Kinds of Cells which compose Stems. — The student has already seen something of cells in the seed, in the roots of seedlings and mature plants, and in several kinds of stems. But he will need to become acquainted with a much larger variety of cells in the stem. The following materials will serve to illustrate some of the most important forms.[1]

Examine with a half-inch objective and one-inch eyepiece (or higher power) these preparations (1–9 below):

Study very carefully each of the sections described, find in it the kind of cell referred to in the corresponding number (1–9) of the following section (104), and make a good sketch of a group of cells of each kind as actually seen under the microscope.[2]

(1) Very thin sections of the epidermis of a potato, some cut parallel to the surface (*tangential*), others cut at right angles to the epidermis.

(2) Thin sections of the green layer of the bark of Forsythia, spindle tree (*Euonymus*), or box-elder (*Negundo*).

(3) Thin cross-sections and longitudinal sections of the inner bark of linden twigs, or of full-grown stems of flax.

(4) Longitudinal sections of the stem of squash or cucumber plants.

(5) Thin cross-sections of young twigs of pine or oak, cut in late summer.

(6) Thin cross-sections and longitudinal sections, cut from pith toward bark (*radial*) of young wood of sycamore, of sassafras, or of box-elder.

(7) Thin longitudinal sections of the stem of castor-oil plant (*Ricinus*) or of the stalk (peduncle) on which the fruit of the banana is supported.

[1] These studies may be made from sections cut by the pupil, by the teacher, or by a professional hand, as circumstances may dictate. The soft bast (No. 4, see p. 91) can best be studied in good prepared sections obtained of the dealers.

[2] Nothing can do so much to make these studies valuable as for the teacher to correct in class the errors of most frequent occurrence in the drawings, by aid of his own *camera lucida* drawings of the same objects.

(8) Thin longitudinal radial sections of sycamore, of sassafras, maple, or box-elder wood.

(9) Thin sections of elder pith, sunflower-stem pith, or of so-called Japanese "rice-paper."

104. Names of the Cells of Bark, Wood, and Pith. — No two varieties of stems will be found to consist of just the

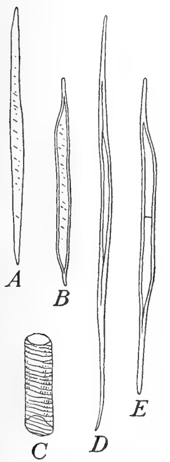


FIG. 59. — *A*, *B*, *C*, *D*, Isolated Wood-Cells and Bast-Cells of Linden.

A, *B*, wood fibers; *C*, piece of a vessel; *D*, bast fiber; *E*, a partitioned, woody fiber from European ivy. (Much magnified.)

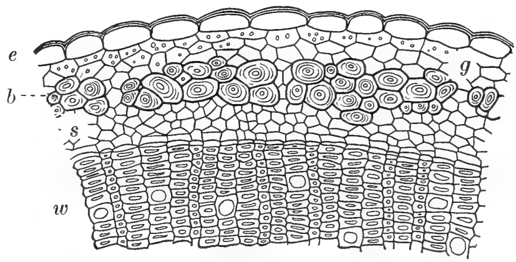


FIG. 60. — Part of Cross-Section of Stem of Flax. (Much magnified.)

e, epidermis; *b*, hard bast; *s*, sieve-cells; *w*, wood.

same kinds of cells, present in the same proportions, but it is easy to refer to illustrations which will serve to identify the kinds of cells found in the studies of the preceding section. They are:

(1) Cork-cells of the epidermis (*e.g.*, flax, Fig. 60, *e*).

(2) Cells of the green bark (*e.g.*, flax, Fig. 60), between *b* and *e*.

(3) Hard bast (Fig. 60).

(4) Soft bast (*e.g.*, flax, Fig. 60, *s*, for the cross-section and (very greatly magnified) Figs. 63, 64, for the lengthwise section).[1]

[1] The sieve-tubes shown in these figures are only one of several kinds of cell found in soft bast, but they are the most peculiar and characteristic ones. (See Strasburger, Noll, Schenk, and Schimper's *Text-Book*, pp. 102–104.)

(5) Cambium (*e.g.*, Fig. 57, *c*).
(6) Wood-cells (*e.g.*, Figs. 58, 72–73).
(7) Vessels or ducts (*e.g.*, Figs. 58 and 62).
(8) Wood parenchyma (*e.g.*, Figs. 58 and 72 in the medullary rays).
(9) Pith (*e.g.*, Figs. 55, 57).

105. Structure of Coniferous Wood. — In the wood of the cone-bearing trees of the pine family regular ducts or

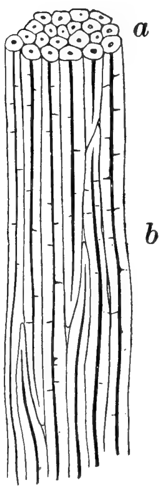


FIG. 61.

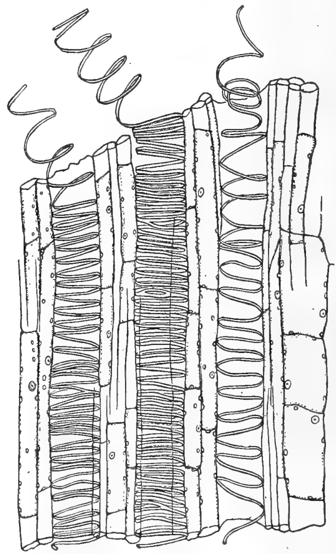


FIG. 62.

FIG. 61. — A Group of Hard Bast Fibers. (Greatly magnified.) *a*, cut-off ends ; *b*, lengthwise section of fibers.

FIG. 62. — A Lengthwise Section (greatly magnified) of a Group of Spiral Vessels from the Stem of Sunflower. At the top of the figure some of the spiral threads which line the vessels are seen partly uncoiled.

vessels are lacking. The main bulk of the wood is composed of long cells (often called *tracheids*), marked with

peculiar pits. These pits, when young, are shaped much like two perforated watch-glasses, placed against a piece of cardboard, with their concave sides toward each other

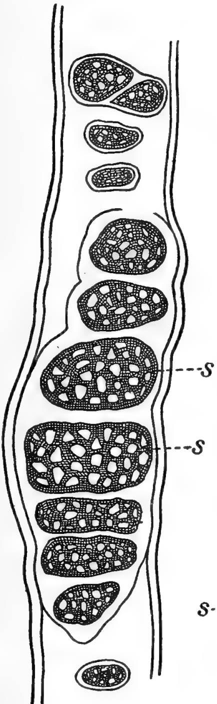


FIG. 63.

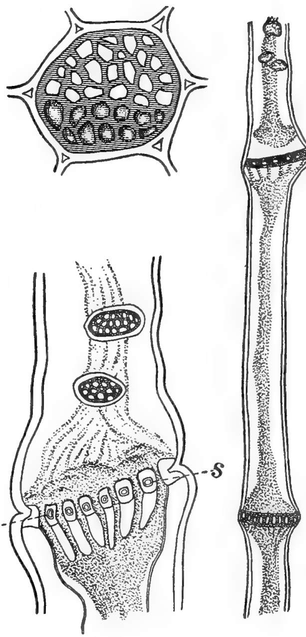


FIG. 64.

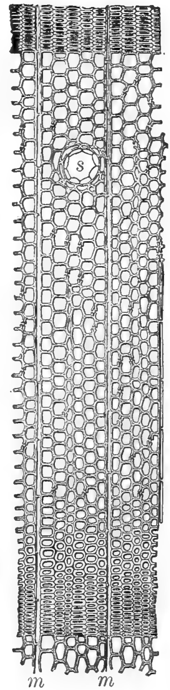


FIG. 65.

FIG. 63. — Part of a Sieve-Tube from Linden.

s, sieve-plates on the cell-wall. (× about 900.)

FIG. 64. — Parts of Sieve-Tubes as found in Plants of the Gourd Family. (Greatly magnified.)

s, *s*, a sieve-plate seen edgewise; above it a similar one, surface view.

FIG. 65. — Cross-Section of Fir Wood.

s, a resin passage; *m*, medullary rays. (Much magnified.)

(see Fig. 66, t''). The cardboard represents a part of the cell-wall common to two adjacent cells, and the watch-glasses are like the convex border bulging into each cell. When the cells grow old the partition in each pit very commonly breaks away and leaves a hole in the cell-wall.

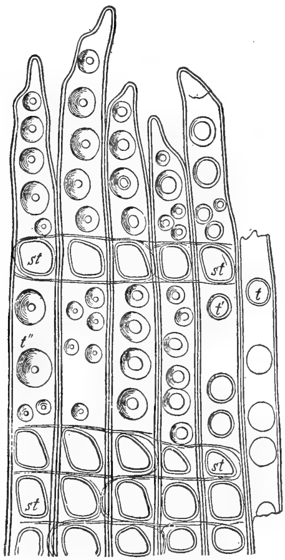


Fig. 66. — Longitudinal Radial Section through a Rapidly Growing Young Branch of Pine.

t, *t'*, *t''*, bordered pits on wood-cells; *st*, large pits where medullary rays lie against wood-cells. (Much magnified.)

106. Tissues. — A mass of similar coöperating cells is called a *tissue*.[1] Two of the principal classes which occur in the stem are *parenchymatous* tissue and *prosenchymatous* tissue. *Parenchyma* is well illustrated by the green layer of the bark, by wood parenchyma, and by pith. Its cells are usually somewhat roundish or cubical, at any rate not many times longer than wide, and at first pretty full of protoplasm. Their walls are not generally very thick.[2] *Prosenchyma*, illustrated by hard bast and masses of wood-cells, consists of thick-walled cells many times longer than wide, containing little protoplasm and often having little or no cell-cavity.

As a rule the stems of the most highly developed plants owe their toughness and their stiffness mainly to prosen-

[1] See Vines' *Students' Text-Book of Botany*, London, 1894, pp. 131–144.
[2] Excepting when they are dead and emptied, like those of old pith.

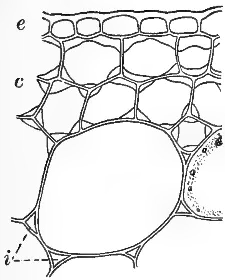


FIG. 67. — Collenchymatous and Other Tissue from Stem of Balsam (*Impatiens*).

e, epidermis; *c*, collenchyma; *i*, intercellular spaces between large parenchyma-cells.

chymatous tissue. In some (particularly in fleshy) stems the stiffness is, however, largely due to *collenchyma*, a kind of parenchyma in which the cells are thickened or reinforced at their angles, as shown in Fig. 67.

107. Early History of Stem-Structure. — In the very young parts of stems, such, for instance, as the growing point between the two rudimentary leaves of a bean-plumule, the cells are all of thin-walled *formative tissue* and look a good deal alike. This condition of things is quickly succeeded by one in which there is a cylinder (appearing in cross-sections of the stem as a ring) of actively growing tissue *x* (Fig. 68, *A*), lying between the cortex *r* and the pith *m*. Soon the cylinder *x* develops into a series of separate fibro-vascular bundles arranged as shown in Fig. 68, *B*, and these again in a short time unite, as shown at *C*. A comparison of this last portion of the figure with that of the

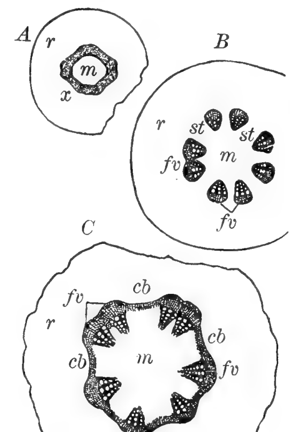


FIG. 68. — Transverse Section through the Hypocotyl of the Castor-Oil Plant at Various Stages.

A, after the root has just appeared outside the testa of the seed; *B*, after the hypocotyl is nearly an inch long; *C*, at the end of germination; *r*, cortex (undeveloped bark); *m*, pith; *st*, medullary rays; *fv*, fibro-vascular bundles; *cb*, layer of tissue which is to develop into cambium. (Considerably magnified.)

one-year-old Aristolochia-stem (Fig. 56) shows a decided similarity between the two. In both cases we have the central pith, the regularly grouped bundles, and cambium (or in Fig. 68, *C*, a tissue which will grow into cambium), — part of it in the bundles and part of it between them.

In the young monocotyledonous stem the grouping of the bundles is less regular than that just explained. This is shown by Fig. 52. A much more important difference consists in the fact that the monocotyledonous stem has usually no permanent living cambium ring. Annual dicotyledons, however, are also destitute of permanent cambium.

108. Secondary Growth. — From the inside of the cambium layer the wood-cells and ducts of the mature stem are produced, while from its outer circumference proceed the new layers of the inner bark, composed largely of sieve-cells and hard bast. From this mode of increase the stems of dicotyledonous plants are called *exogenous*, that is, outside-growing. The presence of the cambium layer on the outside of the wood in early spring is a fact well known to the schoolboy, who pounds the cylinder cut from an elder, willow, or hickory branch until the bark will slip off and so enable him to make a whistle. The sweet taste of this pulpy layer, as found in the white pine, the slippery elm, and the basswood, is a familiar evidence of the nourishment which the cambium layer contains.

With the increase of the fibro-vascular bundles of the wood the space between them, which appears relatively large in Fig. 68, becomes less and less, and the pith, which at first extended freely out toward the circumference of the stem, is at length only represented by thin plates, the medullary rays.

These are of use in storing the food which the plant in cold and temperate climates lays up in the summer and fall for use in the following spring, and in the very young stem they serve as an important channel for the transference of fluids across the stem from bark to pith, or in the

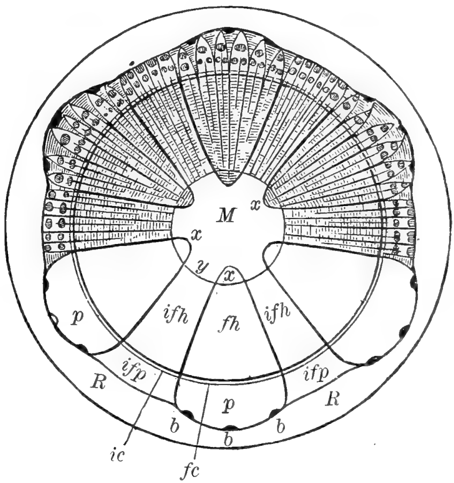


Fig. 69.—Diagram to illustrate Secondary Growth in a Dicotyledonous Stem.

R, the first-formed bark; *p*, mass of sieve-cells; *ifp*, mass of sieve-cells between the original wedges of wood; *fc*, cambium of wedges of wood; *ic*, cambium between wedges; *b*, groups of bast-cells; *fh*, wood of the original wedges; *ifh*, wood formed between wedges; *x*, earliest wood formed; *M*, pith.

reverse direction. On account, perhaps, of their importance to the plants, the cells of the medullary rays are among the longest lived of all plant-cells, retaining their vitality in the beech tree sometimes, it is said, for more than a hundred years.

After the interspaces between the first fibro-vascular bundles have become filled up with wood, the subsequent

growth must take place in the manner shown in Fig. 69. All the cambium, both that of the original wedges of wood, *fc*, and that, *ic*, formed later between these wedges, continues to grow from its inner and from its outer face, and thus causes a permanent increase in the diameter of the stem and a thickening of the bark, which, however, usually at an early period begins to peel off from the outside and thus soon attains a pretty constant thickness.[1] It will be noticed, in the study of dicotyledonous stems more than a year old, that there are no longer any separate fibro-vascular bundles. The process just described has covered the original ring of bundles with layer after layer of later formed wood-cells, and the wood at length is arranged in a hollow cylinder.

It is the lack of any such ring of cambium as is found in dicotyledonous plants, or even of permanent cambium in the separate bundles, that makes it impossible for the trunks of most palm trees (Fig. 54) to grow indefinitely in thickness, like that of an oak or an elm.[2]

109. Grafting. — When the cambium layer of any vigorously growing stem is brought in contact with this layer in another stem of the same kind or a closely similar kind of plant, the two may grow together to form a single stem or branch. This process is called *grafting*, and is much resorted to in order to secure apples, pears, etc., of any desired kind. A twig from a tree of the chosen variety is grafted on to any kind of tree *of the same species* (or sometimes a related species), and the resulting stems will bear the wished-for kind of fruit. Sometimes grafting comes

[1] See Vines' *Students' Text-Book of Botany*, London, 1894, pp. 211, 212.

[2] See, however, Strasburger, Noll, Schenk and Schimper's *Text-Book*, pp. 138, 139.

about naturally by the branches of a tree chafing against one another until the bark is worn away and the cambium layer of each is in contact with that of the other, or two separate trees may be joined by natural grafting, as is shown in Fig. 70.

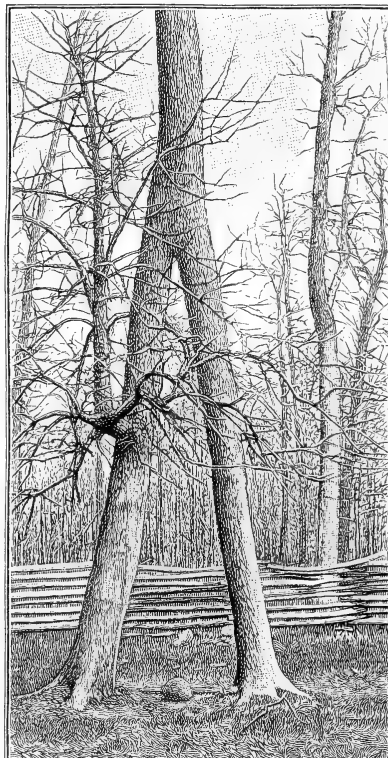


FIG. 70. — Two Ash Trees naturally grafted together.

110. Stem-Structure of Climbing Shrubs. — Some of the most remarkable kinds of dicotyledonous stems are found in climbing shrubs. The structure of many of these is too complicated to be discussed in a botany for beginners, but one point in regard to them is of much interest. The bundles (as seen in the clematis and shown in Fig. 56) are much more distinct than in most other woody stems. Even after several years of growth the wood is often found to be arranged in a number of flattish twisted strands. It is evident that this is for the sake of leaving the stem flexible for twining purposes, just as a wire cable is adapted to be wound about posts or other supports, while

a solid steel or iron rod of the same size would be too stiff for this use.

111. The Dicotyledonous Stem, thickened by Secondary Growth. — Cut off, as smoothly as possible, a small branch of hickory and one of white oak above and below each of the rings of scars already mentioned (Sect. 77), and count the rings of wood above and below each ring of scars.

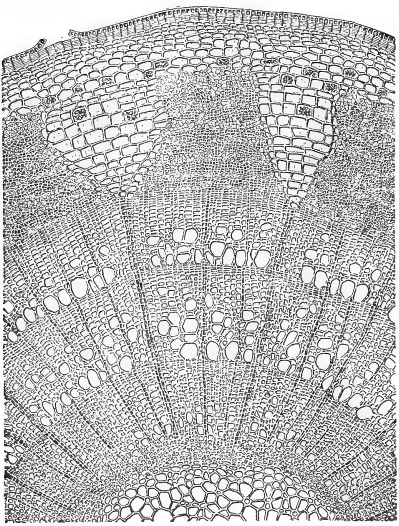


FIG. 71. — Cross-Section of a Three-Year-Old Linden Twig. (Much magnified.)

P, epidermis and corky layer of the bark; *Phl*, bast; *C*, cambium layer; *JR*, annual rings of wood.

How do the numbers correspond? What does this indicate?

Count the rings of wood on the cut-off ends of large billets of some of the following woods: locust, chestnut, sycamore, oak, hickory.

Do the successive rings of the same tree agree in thickness?

Why? or why not?

Does the thickness of the rings appear uniform all the way round the stick of wood? If not, the reason in the case of an upright stem (trunk) is perhaps that there was a greater spread of leaves on the side where the rings are thickest[1] or because there was unequal pressure, caused by bending before the wind.

Do the rings of any one kind of tree agree in thickness with those of all the other kinds? What does this show?

In all the woods examined look for:

(*a*) Contrasts in color between the heartwood and the sapwood.[2]

[1] See Sect. 118.

[2] This is admirably shown in red cedar, black walnut, barberry, black locust and osage orange.

(*b*) The narrow lines running in very young stems pretty straight from pith to bark, in older wood extending only a little of the way from center to bark, the *medullary rays*, shown in Fig. 72.[1]

(*c*) The wedge-shaped masses of wood between these.

(*d*) The pores which are so grouped as to mark the divisions between successive rings. These pores indicate the cross-sections of *vessels* or *ducts*. Note the distribution of the vessels in the rings to which they belong, com-

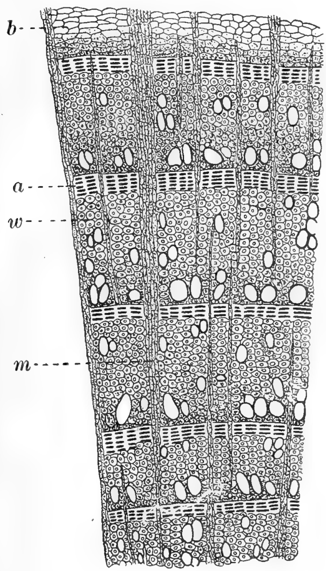


FIG. 72. — Cross-Section of Beech-Wood. *b*, bark; *a*, flattened cells formed near end of each year's growth; *w*, regular wood-cells; *m*, medullary ray.

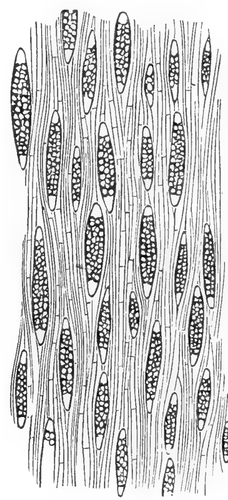


FIG. 73. — Longitudinal Section of Mahogany at Right Angles to Medullary Rays, showing Cut-off Ends. (Much magnified.)

pare this with Figs. 58, 72, and decide at what season of the year the largest ducts are mainly produced. Make a careful drawing of the end-section of one billet of wood, natural size.

Cut off a grapevine several years old and notice the great size of

[1] These and many other important things are admirably shown in the thin wood-sections furnished for $4 per set of 24 by R. B. Hough, Lowville, N. Y.

the vessels. Examine the smoothly planed surface of a billet of red oak that has been split through the middle of the tree (quartered oak), and note the large shining plates formed by the medullary rays.

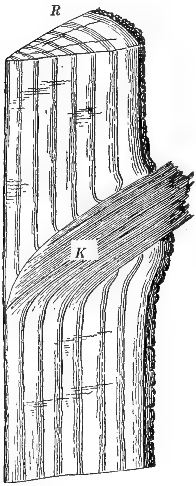


FIG. 74. — Formation of a Knot in a Tree-Trunk.

R, cut-off end of stick, showing annual rings; *K*, knot, formed by growth of a branch.

Look at another stick that has been planed away from the outside until a good-sized flat surface is shown, and see how the medullary rays are here represented only by their edges.

112. Interruption of Annual Rings by Branches; Knots. — When a leaf-bud is formed on the trunk or branch of a dicotyledonous tree, it is connected with the wood by fibro-vascular bundles. As the bud develops into a branch, the few bundles which it originally possessed increase greatly in number, and at length, as the branch grows, form a cylinder of wood which cuts across the annual rings, as shown in Fig. 74. This interruption to the rings is a knot, such as one often sees in boards and planks. If the branch dies long before the tree does, the knot may be buried under many rings of wood. What is known as clear lumber is obtained from trees that have grown in a dense forest, so that the lower branches of the larger trees were killed by the shade many years before the tree was felled.

In pruning fruit trees or shade trees the branches which are removed should be cut close to the trunk. If this is done, the growth of the trunk will bury the scar before decay sets in.

113. Comparison of the Monocotyledonous and the Dicotyledonous Stem.[1]

	Monocotyledonous Stem	Dicotyledonous Stem
General Structure.	A hard rind of rather uniform structure. Bundles intermixed with the pith.	A complex bark, usually on young shoots consisting of a corky layer, a green layer, and a layer of bast. Wood in annual rings. Pith in a cylinder at the center.
Structure of Bundles.	Bundles *closed*, that is, without permanent cambium.	Bundles *open*, with permanent cambium.
Growth in Thickness.	Cells of mature parts of stem expand somewhat, but (in most palms) new ones are not found.	New wood-cells formed throughout growing season from cambium ring.

114. Review Sketches and Diagrams.

(1) Monocotyledonous stem (lengthwise section).
(2) Dicotyledonous stem (lengthwise section).
(3) First appearance of bundles in dicotyledonous stem.
(4) Dicotyledonous stem five years or more old (cross-section).
(5) Various bark-cells.
(6) Various cells from wood.
(7) Pith-cells.
(8) Collenchyma-cells.

[1] This comparison applies only to most of the woody or tree-like stems.

CHAPTER VII

LIVING PARTS OF THE STEM; WORK OF THE STEM

115. Active Portions of the Stems of Trees and Shrubs. — In annual plants generally and in the very young shoots of shrubs and trees there are *stomata* or breathing pores which occur abundantly in the epidermis, serving for the admission of air and the escape of moisture, while the green layer of the bark answers the same purpose that is served by the green pulp of the leaf (Chapter XI). For years, too, the spongy lenticels, which succeed the stomata and occur scattered over the external surface of the bark of trees and shrubs, serve to admit air to the interior of the stem. The lenticels at first appear as roundish spots, of very small size, but as the twig or shoot on which they occur increases in diameter the lenticel becomes spread out at right angles to the length of the stem, so that it sometimes becomes a longer transverse slit or scar on the bark, as in the cherry and the birch. But in the trunk of a large tree no part of the bark except the inner layer is alive. The older portions of the bark, such as the highly developed cork of the cork-oak, from which the ordinary stoppers for bottles are made, sometimes cling for years after they are dead and useless except as a protection for the parts beneath against mechanical injuries or against cold. But in many cases, as in the shell-bark hickory and the grapevine, the old bark soon falls off in strips; in birches it finally peels off in bands around the stem.

The cambium layer is very much alive, and so is the young outer portion of the wood. Testing this "sap-wood," particularly in winter, shows that it is rich in starch and proteids.

The heartwood of a full-grown tree is hardly living, unless the cells of the medullary rays retain their vitality, and so it may be that wood of this kind is useful to the tree mainly by giving stiffness to the trunk and larger branches, thus preventing them from being easily broken by storms.

It is, therefore, possible for a tree to flourish, sometimes for centuries, after the heartwood has much of it rotted away and left the interior of the trunk hollow, as shown in Fig. 75.

116. Uses of the Components of the Stem. — There is a marked division of labor among the various groups of cells that make up the stem of ordinary dicotyledons, particularly in the stems of trees, and it will be best to explain the uses of the kinds of cells as found in trees, rather than in herbaceous plants. A few of the ascertained uses of the various tissues are these:

The pith forms a large part of the bulk of very young shoots, since it is a part of the tissue of comparatively simple structure amid which the fibro-vascular bundles arise. In mature stems it becomes rather unimportant, though it often continues for a long time to act as a storehouse of food.

The medullary rays in the young shoot serve as a channel for the transference of water and plant-food in a liquid form across the stem, and they often contain much stored food.

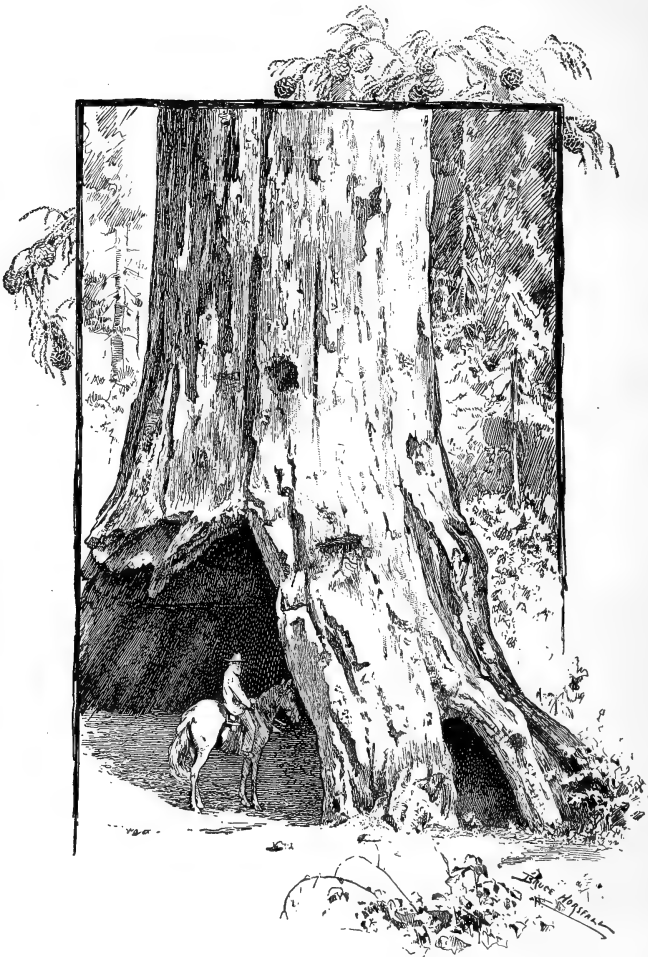


FIG. 75.—Pioneer's Cabin, a Very Large Hollow Sequoia.

The vessels carry water upward and (sometimes) air downward through the stem.

The wood-cells of the heartwood are useful only to give

stiffness to the stem. Those of the sapwood, in addition to this work, have to carry most of the water from the roots to the leaves and other distant portions of the plant.

The cambium layer is the region in which the annual growth of the tree takes place (Figs. 69, 71).

The most important portion of the inner bark is that which consists of sieve-tubes, for in these digested and elaborated plant-food is carried from the leaves toward the roots.

The green layer of the bark in young shoots does much toward collecting nutrient substances, or raw materials, and preparing the food of the plant from air and water, but this work may be best explained in connection with the study of the leaf (Chapter XI).

117. Movement of Water in the Stem. — The student has already learned that large quantities of water are taken up by the roots of plants.

Having become somewhat acquainted with the structure of the stem, he is now in a position to investigate the question how the various fluids, commonly known as sap, travel about in it.[1] It is important to notice that sap is by no means the same substance everywhere and at all times. As it first makes its way by osmotic action inward through the root-hairs of the growing plant it differs but little from ordinary spring water or well water. The liquid which flows from the cut stem of a "bleeding" grapevine which has been pruned just before the buds have begun to burst in the spring, is mainly water with a little dissolved mucilaginous material. The sap which is

[1] See the paper on "The So-called Sap of Trees and its Movements," by Professor Charles R. Barnes, *Science*, Vol. XXI, p. 535.

obtained from maple trees in late winter or early spring, and is boiled down for syrup or sugar, is still richer in nutritious material than the water of the grapevine, while the elaborated sap which is sent so abundantly into the ear of corn, at its period of filling out, or into the growing pods of beans and peas, or into the rapidly forming acorn or the chestnut, contains great stores of food, suited to sustain plant or animal life.

EXPERIMENT XXI

Rise of Water in Stems. — Cut some short branches from an apple tree or a cherry tree and stand the lower end of each in red ink; try the same experiment with twigs of oak, ash, or other porous wood, and after some hours[1] examine with the magnifying glass and with the microscope, using the 2-inch objective, successive cross-sections of one or more twigs of each kind. Note exactly the portions through which the ink has traveled. Pull off the leaves from one of the stems after standing in the eosin solution, and notice the spots on the leaf-scar through which the eosin has traveled. These spots show the positions of the *leaf-traces*, or fibro-vascular bundles, connecting the stem and the leaf. Repeat with several potatoes, cut crosswise through the middle. Try also some monocotyledonous stems, such as those of the lily or asparagus. For the sake of comparison between roots and stems, treat any convenient root, such as a parsnip, in the same way.

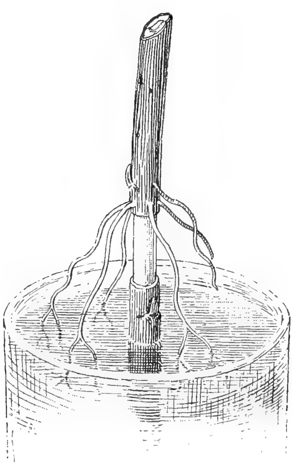


FIG. 76. — A Cutting girdled and sending down Roots from the Upper Edge of the Girdled Ring.

[1] If the twigs are leafy and the room is warm, only from 5 to 30 minutes may be necessary.

Examine longitudinal sections of some of the twigs, the potatoes, and the roots. In drawing conclusions about the channels through which the ink has risen (those through which the newly absorbed soil-water most readily travels), bear in mind the fact that a slow soakage of the red ink will take place in all directions, and therefore pay attention only to the strongly colored spots or lines.

What conclusions can be drawn from this experiment as to the course followed by the sap?

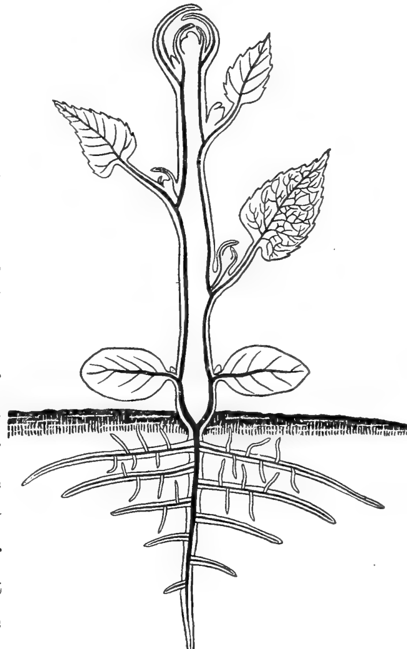


FIG. 77. — Channels for the Movement of Water, upward and downward.

The heavy black lines in roots, stems, and leaves show the course of the fibro-vascular bundles through which the principal movements of water take place.

From the familiar facts that ordinary forest trees apparently flourish as well after the almost complete decay and removal of their heartwood, and that many kinds will live and grow for a considerable time after a ring of bark extending all round the trunk has been removed, it may readily be inferred that the crude sap in trees must rise through some portion of the newer layers of the wood. A tree girdled by the removal of a ring of sapwood promptly dies.

118. Downward Movement of Liquids. — Most dicotyledonous stems, when stripped of a ring of bark and then

stood in water, as shown in Fig. 76, and covered with a bell-jar, develop roots only at or near the upper edge of the stripped portion,[1] and this would seem to prove that such stems send their building material — the elaborated sap — largely at any rate down through the bark. Its course is undoubtedly for the most part through the sieve-cells (Figs. 63, 64), which are admirably adapted to convey liquids. In addition to these general upward and downward movements of sap, there must be local transfers laterally through the stem, and these are at times of much importance to the plant.

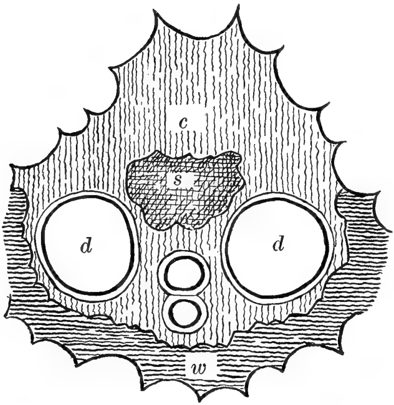


FIG. 78. — Diagrammatic Cross-Section of a Bundle from Sugar-Cane, showing Channels for Air and Water. (Magnified.)

Air travels downward through the two large ducts *d* (and the two smaller ones between them). Water travels upward through the ducts and through the wood-cells in the region marked *w*. Water with dissolved plant-food travels downward through the sieve-cells in the region marked *s*.

Since the liquid building material travels straight down the stem, that side of the stem on which the manufacture of such material is going on most rapidly should grow fastest.

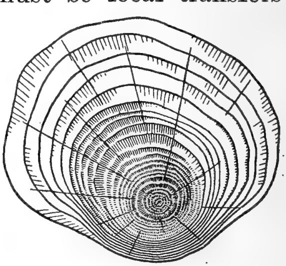


FIG. 79. — Unequal Growth of Rings of Wood in nearly Horizontal Stem of a Juniper. (Natural size.)

[1] This may be made the subject of a protracted class-room experiment. Strong shoots of willow should be used for the purpose.

Plant-food is made out of the raw materials by the leaves, and so the more leafy side of a tree forms thicker rings than the less leafy side, as shown in Fig. 79.

119. Rate of Movement of Water in the Stem. — There are many practical difficulties in the way of ascertaining exactly how fast the watery sap travels from the root to the leaves. It is, however, easy to illustrate experimentally the fact that it does rise, and to give an approximate idea of the time required for its ascent. The best experiment for beginners is one which deals with an entire plant under natural conditions.

EXPERIMENT XXII

Wilting and Recovery. — Allow a fuchsia or a hydrangea[1] which is growing in a flower-pot to wilt considerably for lack of watering. Then water it freely and record the time required for the leaves to begin to recover their natural appearance and position, and the time fully to recover.

The former interval of time will give a very rough idea of the time of transfer of water through the roots and the stem of the plant. From this, by measuring the approximate distance traveled, a calculation could be made of the number of inches per minute that water travels in this particular kind of plant, through a route which is partly roots, partly stem, and partly petiole. Still another method is to treat leafy stems as the student in Exp. XXI treated the twigs which he was examining, and note carefully the rate of ascent of the coloring liquid. This plan is likely to give results that are too low, still it is of some use. It has given results varying from 34 inches per

[1] *Hydrangea Hortensia.*

hour for the willow to 880 inches per hour for the sunflower. A better method is to introduce the roots of the plant which is being experimented upon into a weak solution of some chemical substance which is harmless to the plant and which can readily be detected anywhere in the tissues of the plant by chemical tests. Proper tests are then applied to portions of the stem which are cut from the plant at short intervals of time.

Compounds of the metal lithium are well adapted for use in this mode of experimentation.

120. Causes of Movements of Water in the Stem. — Some of the phenomena of osmosis were explained in Sect. 62, and the work of the root-hairs was described as due to osmotic action.

Root-pressure (Sect. 66), being apparently able to sustain a column of water only 80 or 90 feet high at the most, and usually less than half this amount, would be quite insufficient to raise the sap to the tops of the tallest trees, since many kinds grow to a height of more than 100 feet. Our Californian "big trees," or Sequoias, reach the height of over 300 feet, and an Australian species of Eucalyptus, it is said, sometimes towers up to 470 feet. Root-pressure, then, may serve to start the soil-water on its upward journey, but some other force or forces must step in to carry it the rest of the way. What these other forces are is still a matter of discussion among botanists.

The slower inward and downward movement of the sap may be explained as due to osmosis. For instance, in the case of growing wood-cells, sugary sap descending from the leaves into the stem gives up part of its sugar to form the cellulose of which the wood-cells are being made.

This loss of sugar would leave the sap rather more watery than usual, and osmosis would carry it from the growing wood to the leaves, while at the same time a slow transfer of the dissolved sugar will be set up from leaves to wood. The water, as fast as it reaches the leaves, will be thrown off in the form of vapor, so that they will not become distended with water, while the sugar will be changed into cellulose and built into new wood-cells as fast as it reaches the region where such cells are being formed.

Plants in general[1] readily change starch to sugar, and sugar to starch. When they are depositing starch in any part of the root or stem for future use, the withdrawal of sugar from those portions of the sap which contain it most abundantly gives rise to a slow movement of dissolved particles of sugar in the direction of the region where starch is being laid up.

121. Storage of Food in the Stem.—The reason why the plant may profit by laying up a food supply somewhere inside its tissues has already been suggested (Sect. 91).

The most remarkable instance of storage of food in the stem is probably that of sago-palms, which contain an enormous amount, sometimes as much as 800 pounds, of starchy material in a single trunk. But the commoner plants of temperate regions furnish plenty of examples of deposits of food in the stem. As in the case of seeds and roots, starch constitutes one of the most important kinds of this reserve material of the stem, and since it is easier to detect than any other food material which the plant stores, the student will do well to spend time in looking for starch only.

[1] Not including most of the flowerless and very low and simple kinds.

Cut thin cross-sections of twigs of some common deciduous tree or shrub, in its early winter condition, moisten with iodine solution, and examine for starch with a moderately high power of the microscope. Sketch the section with a pencil, coloring the starchy portions with blue ink, used with a mapping pen, and describe exactly in what portions the starch is deposited.

122. Storage in Underground Stems. — The branches and trunk of a tree furnish the most convenient place in which to deposit food during winter to begin the growth of the following spring. But in those plants which die down to the ground at the beginning of winter the storage must be either in the roots, as has been described in Sect. 58, or in underground portions of the stem.

Rootstocks, tubers, and bulbs seem to have been developed by plants to answer as storehouses through the winter (or in some countries through the dry season) for the reserve materials which the plant has accumulated during the growing season. The commonest tuber is the potato, and this fact and the points of interest which it represents make it especially desirable to use for a study of the underground stem in a form most highly specialized for the storage of starch and other valuable products.

123. A Typical Tuber: the Potato. — Sketch the general outline of a potato, showing the attachment to the stem from which it grew.[1]

Note the distribution of the "eyes," — are they opposite or alternate? Examine them closely with the magnifying glass and then with the lowest power of the microscope. What do they appear to be?

If the potato is a stem, it may branch, — look over a lot of potatoes to try to find a branching specimen. If such a one is secured, sketch it.

[1] Examination of a lot of potatoes will usually discover specimens with an inch or more of attached stem.

Note the little scale overhanging the edge of the eye, and see if you can ascertain what this scale represents.

Cut the potato across, and notice the faint broken line which forms a sort of oval figure some distance inside the skin.

Place the cut surface in eosin solution, allow the potato to stand so for many hours, and then examine, by slicing off pieces parallel to the cut surface, to see how far and into what portions the solution has penetrated. Refer to the notes on the study of the parsnip (Sect. 56), and see how far the behavior of the potato treated with eosin solution agrees with that of the parsnip so treated.

Cut a thin section at right angles to the skin, and examine with a high power. Moisten the section with iodine solution and examine again.

If possible, secure a potato which has been sprouting in a warm place for a month or more (the longer the better), and look near the origins of the sprouts for evidences of the loss of material from the tuber.

EXPERIMENT XXIII

Use of the Corky Layer. — Carefully weigh a potato, then pare another larger one, and cut portions from it until its weight is made approximately equal to that of the first one. Expose both freely to the air for some days and reweigh. What does the result show in regard to the use of the corky layer of the skin?

124. Morphology of the Potato. — It is evident that in the potato we have to do with a very greatly modified form of stem. The corky layer of the bark is well represented, and the loose cellular layer beneath is very greatly developed; wood is almost lacking, being present only in the very narrow ring which was stained by the red ink, but the pith is greatly developed and constitutes the principal bulk of the tuber. All this is readily understood if we consider that the tuber, buried in and supported by the earth, does not need the kinds of tissue which give

strength, but only those which are well adapted to store the requisite amount of food.

125. Structure of a Bulb; the Onion. — Examine the external appearance of the onion and observe the thin membranaceous skin which covers it. This skin consists of the broad sheathing bases of the outer leaves which grew on the onion plant during the summer. Remove these and notice the thick scales (also formed from bases of leaves as shown in Fig. 48) which make up the substance of the bulb.

Make a transverse section of the onion at about the middle and sketch the rings of which it is composed. Cut a thin section from the interior of the bulb, examine with a moderate power of the microscope, and note the thin-walled cells of which it is composed.

Split another onion from top to bottom and try to find:

(*a*) The *plate* or broad flattened stem inside at the base (Fig. 47).

(*b*) The central bud.

(*c*) The bulb-scales.

(*d*) In some onions (particularly large, irregular ones) the bulblets or side buds arising in the axes of the scales near the base.

Test the cut surface for starch.

126. Sugar in the Onion. — *Grape sugar* is an important substance among those stored for food by the plant. It received its name from the fact that it was formerly obtained for chemical examination from grapes. Old dry raisins usually show little masses of whitish material scattered over the skin which are nearly pure grape sugar. Commercially it is now manufactured on an enormous scale from starch by boiling with diluted sulphuric acid. In the plant it is made from starch by processes as yet imperfectly understood, and another sugar, called *maltose*, is made from starch in the seed during germination.

Both grape sugar and maltose (and hardly any other substances) have the power of producing a yellow or

orange color and throwing down an orange or reddish deposit, when they are added to a brilliant blue alkaline solution of copper, known as *Fehling's solution.*[1] The color or deposit will not appear until the solution has been heated to boiling.

EXPERIMENT XXIV

Testing for Grape Sugar. — Heat to boiling in a test-tube or a small beaker some weak syrup of grape sugar or some honey, much diluted with water. Add Fehling's solution, a few drops at a time, until a decided orange color appears. Repeat the test with the water in which some slices of onion have been boiled, filtering the water through a paper filter and heating again to boiling before adding the test solution.[2]

127. Proteids in the Onion. — Since the onion grows so rapidly on being planted in the spring, there must be a large supply of food in the bulb; there may be other substances present besides sugar.

EXPERIMENT XXV

Testing an Onion for Other Stored Food. — Test a rather thick slice of onion by heating it in a porcelain evaporating dish with a little strong nitric acid until the latter begins to boil and the onion becomes somewhat softened.[3] Rinse off the slice of onion in a stream of water, then pour on it a few drops of ammonium hydrate and observe any change of color. What is proved? See Sect. 29.

128. Tabular Review of Experiments.

[Continue the table from Sect. 74.]

[1] For the preparation of the solution see Handbook.

[2] The deposit will in this case, even if orange at first, finally become black, probably owing to the presence of sulphur in the onion.

[3] Do not allow the acid to touch the clothing, the hands, or any metallic object.

129. Review Summary of Work of Stem.

Channels for upward movement of water	in young dicotyledonous stems	.
	in dicotyledonous stems several years old	. . . .
	in monocotyledonous stems	. .
Channels for downward movement of water	in dicotyledonous stems	. . .
	in monocotyledonous stems	. .
Channels for transverse movements		. . . .
Rate of upward movement		. . . .
Storage of plant-food	where stored	. . . .
	kinds stored	. . . .
	uses	. . . .

CHAPTER VIII

BUDS

130. Structure of Buds. — While studying twigs in their winter condition, as directed in Sects. 77, 78, the student had occasion to notice the presence, position, and arrangement of buds on the branch, but he was not called upon to look into the details of their structure. The most natural time to do this is just before the study of the leaf is begun, since leafy stems spring from buds, and the rudiments of leaves in some form must be found in buds.

131. The Horse-Chestnut Bud. — Examine one of the lateral buds on a twig in its winter or early spring condition.[1]

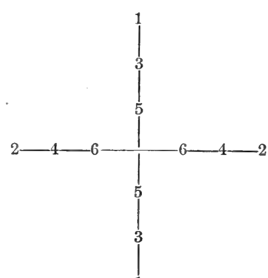
Make a sketch of the external appearance of the buds as seen with a magnifying glass.

How do the scales with which it is covered lie with reference to those beneath them?

Notice the sticky coating on the scales.

Are the scales opposite or alternate?

Remove the scales in pairs, placing them in order on a sheet of paper, thus:



Make the distance from 1 to 1 as much as 6 or 8 inches.

How many pairs are found?

Observe as the scales are removed whether the sticky coating is

[1] The best possible time for this examination is just as the buds are beginning to swell slightly in the spring. The bud of buckeye or of cottonwood will do for this examination, though each is on a good deal smaller scale than the horse-chestnut bud. Buds may be forced to open early by placing twigs in water in a very warm, light place for many weeks.

thicker on the outside or the inside of each scale, and whether it is equally abundant on all the successive pairs.

What is the probable use of this coating?

Note the delicate veining of some of the scales as seen through the magnifying glass. What does this mean?

Fig. 80. — Dissected Bud of Buckeye (*Æsculus macrostachya*), showing Transitions from Bud-Scales to Leaves.

Inside the innermost pair are found two forked woolly objects; what are these?

Compare with Figs. 87 and 107.

Their shape could be more readily observed if the woolly coating were removed.

Can you suggest a use for the woolly coating?

Examine a terminal bud in the same way in which you have just studied the lateral bud.

Does it contain any parts not found in the other?

What is the appearance of these parts?

What do they represent?

If there is any doubt about their nature, study them further on a horse-chestnut tree during and immediately after the process of leafing out in the spring.

For comparison study at least one of the following kinds of buds in their winter or early spring condition: hickory, butternut, beech, ash, magnolia (or tulip tree), lilac, balm of Gilead, cottonwood, cultivated cherry.[1]

[1] Consult the account of the mode of studying buds in Professor W. F. Ganong's *Teaching Botanist*, pp. 208–210. If some of the buds are studied at home, pupils will have a better chance to examine at leisure the unfolding process.

132. Nature of Bud-Scales. — The fact that the bud-scales are in certain cases merely imperfectly developed leaves or leaf-stalks is often clearly manifest from the series of steps connecting the bud-scale on the one hand with the young leaf on the other, which may be found in many opening buds, as illustrated by Fig. 80. In other buds the scales are not imperfect leaves, but the little appendages (*stipules*, Figs. 98, 99) which occur at the bases of leaves. This kind of bud-scale is especially well shown in the magnolia and the tulip tree.

133. Naked Buds. — All of the buds above mentioned are *winter buds*, capable of living through the colder months of the year, and are scaly buds.

In the herbs of temperate climates, and even in shrubs and trees of tropical regions, the buds are often *naked*, that is, nearly or quite destitute of scaly coverings (Fig. 81).

Make a study of the naked buds of any convenient herb, such as one of the common "geraniums" (*Pelargonium*), and record what you find in it.

Fig. 81. — Tip of Branch of *Ailanthus* in Winter Condition, showing very Large Leaf-Scars and nearly Naked Buds.

134. Position of Buds. — The distinction between *lateral* and *terminal* buds has already been alluded to.

The plumule is the first terminal bud which the plant produces. Lateral buds are usually *axillary*, as shown in Fig. 82, that is, they grow in the angle formed by the leaf with the stem (Latin *axilla*, armpit). But not infrequently there are several buds grouped in some way about

FIG. 82. — Alternate Leaves of Cultivated Cherry, with Buds in their Axils, in October.

a single leaf-axil, either one above the other, as in the butternut (Fig. 84), or grouped side by side, as in the red maple, the cherry, and the box-elder (Fig. 83).

In these cases all the buds except the axillary one are called *accessory* or *supernumerary* buds.

135. Leaf-Buds and Flower-Buds; the Bud an Undeveloped Branch. — Such buds as the student has so far

examined for himself are not large enough to show in the most obvious way the relation of the parts and their real nature.

Fortunately, it is easy to obtain a gigantic terminal bud which illustrates perfectly the structure and arrangement of the parts of buds in general.

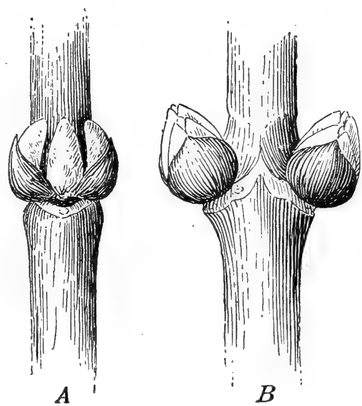


FIG. 83. — Accessory Buds of Box-Elder (*Negundo*). (Magnified.)

A, front view of group.
B, two groups seen in profile.

Examine and sketch a rather small, firm cabbage, preferably a red one, which has been split lengthwise through the center[1] and note

(*a*) The short, thick, conical stem.

(*b*) The crowded leaves which arise from the stem, the lower and outer ones largest and most mature, the upper and innermost ones the smallest of the series.

(*c*) The axillary buds, found in the angles made by some leaves with the stem.

Compare the section of the cabbage with Fig. 86.

Most of the buds so far considered were *leaf-buds*, that is, the parts inside of the scales would develop into leaves, and their central axes into stems; but some were *mixed buds*, that is, they contained both leaves and flowers in an undeveloped condition.

Flower-buds contain the rudiments of flowers only.

Sometimes, as in the black walnut and the butternut, the leaf-buds and flower-buds are readily distinguishable

[1] Half of a cabbage will be enough for the entire division.

by their difference in form, while in other cases, as in the cultivated cherry, the difference in form is but slight.

The rings of scars about the twig, shown in Figs. 82 and 85, mark the place where the bases of bud-scales were attached. A little examination of the part of the twig which lies outside of this ring, as shown in Fig. 82, will lead one to the conclusion that this portion has all grown in the one spring and summer since the bud-scales of that particular ring dropped off. Following out this suggestion, it is easy to reckon the age of any moderately old portion of a branch, since it is equal to the number of segments between the rings. In rapidly growing shoots of willow, poplar, and similar trees, 5 or 10 feet of the length may be the growth of a single year, while in the lateral twigs of the hickory, apple, or cherry the yearly increase may be but a fraction of an inch. Such fruiting "spurs" as are shown in Fig. 85 are of little use in the permanent growth of the tree, and poplars, elms, soft maples and other trees shed the oldest of these every year. Whatever the amount of this growth, it is but the lengthening out and development of the bud, which may be regarded as an undeveloped stem or branch, with its internodes so shortened that successive leaves seem almost to spring from the same point.

FIG. 84. — Accessory Buds of Butternut. (Reduced.)

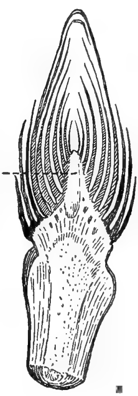
l, leaf-scar; *ax*, axillary bud; *a*, *a′*, accessory buds; *t*, terminal bud.

136. Vernation. — Procure a considerable number of buds which are just about to burst, and others which have begun to open. Cut each across with a razor or very sharp scalpel; examine first with the magnifying glass, and then with the lowest power of the microscope. Pick to pieces other buds of the same kinds under the magnifying glass, and report upon the manner in which the leaves are packed away.

The arrangement of leaves in the bud is called *vernation;* some of the principal modes are shown in Fig. 86.

Fig. 85. — A slowly grown Twig of Cherry, 3 inches long and about ten years old.

The pointed bud *l* is a leaf-bud; the more obtuse accessory buds *f*, *f* are flower-buds.



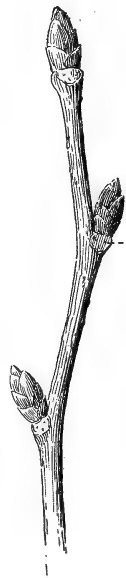


Fig. 86.

B, a twig of European elm; *A*, a longitudinal section of the buds of *B* (considerably magnified); *ax*, the axis of the bud, which will elongate into a shoot; *sc*, leaf-scars.

In the cherry the two halves of the leaf are folded together flat, with the under surfaces outward; in the walnut the separate *leaflets*, or parts of the leaf, are folded

flat and then grouped into a sort of cone; in the snowball each half of the leaf is plaited in a somewhat fan-like manner, and the edges of the two halves are then brought round so as to meet; in the lady's mantle the fan-like plaiting is very distinct; in the wood sorrel each leaflet

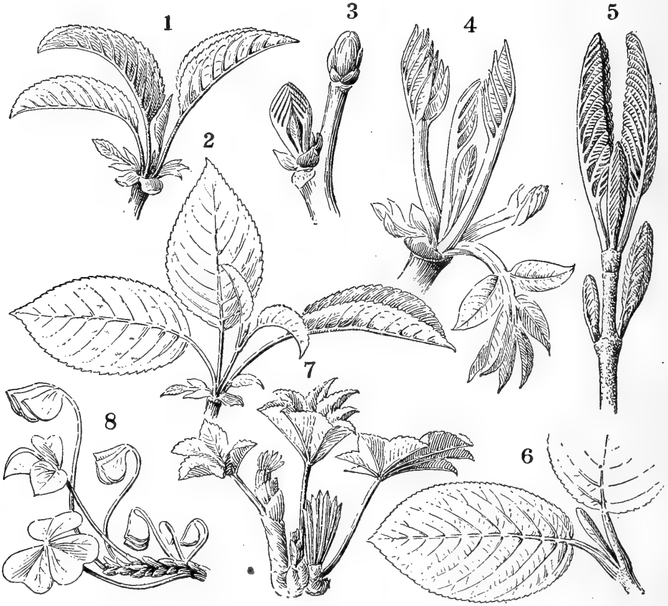


FIG. 87, I.—Types of Vernation.
1, 2, Cherry; 3, 4, European walnut; 5, 6, snowball; 7, lady's mantle; 8, oxalis.

is folded smoothly, and then the three leaflets packed closely side by side. All these modes of vernation and many others have received accurate descriptive names by which they are known to botanists.

137. Importance of Vernation.—The significance of vernation is best understood by considering that there are two

important purposes to be served; the leaves must be stowed as closely as possible in the bud, and upon beginning to open they must be protected from too great heat and dryness until they have reached a certain degree of firmness. It may be inferred from Fig. 87, I, that it is common for very young leaves to stand vertically. This protects them considerably from the scorching effect of the sun at the hottest part of the day. Many young leaves, as, for instance, those of the silver-leafed poplar, the pear, the beech, and the mountain ash, are sheltered and pro-

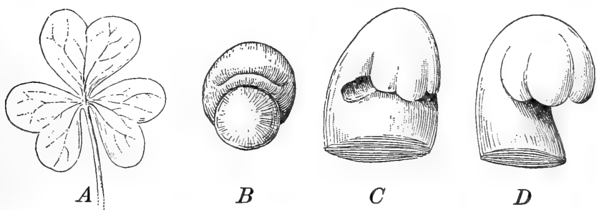


FIG. 87, II.—Development of an Oxalis Leaf.

A, full-grown leaf; *B*, rudimentary leaf, the leaflets not yet evident; *C*, more advanced stage, the leaflets appearing; *D*, a still more advanced stage; *B*, *C*, and *D*, considerably magnified.

tected from the attacks of small insects by a coating of wool or down, which they afterwards lose. Those of the tulip tree are enclosed for a little time in thin pouches, which serve as bud-scales, and thus entirely shielded from direct contact with the outside air (see Sect. 117).

138. Dormant Buds. — Generally some of the buds on a branch remain undeveloped in the spring, when the other buds are beginning to grow, and this inactive condition may last for many seasons. Finally the bud may die, or some injury to the tree may destroy so many other buds as to leave the dormant ones an extra supply of food, and

this, with other causes, may force them to develop and to grow into branches.

Sometimes the tree altogether fails to produce buds at places where they would regularly occur. In the lilac the terminal bud usually fails to appear, and the result is constant forking of the branches.

139. Adventitious Buds. — Buds which occur in irregular places, that is, not terminal nor in or near the axils of leaves, are called *adventitious buds;* they may spring from the roots, as in the silver-leafed poplar, or from the sides of the trunk, as in our American elm. In many trees, for instance willows and maples, they are sure to appear after the trees have been cut back. Willows are thus cut back or *pollarded*, as shown in Plate II, in order to cause them to produce a large crop of slender twigs suitable for basket-making.

Leaves rarely produce buds, but a few kinds do so when they are injured. Those of the bryophyllum, a plant allied to the garden live-for-ever, when they are removed from the plant while they are still green and fresh, almost always send out buds from the margin. These do not appear at random but are borne at the notches in the leaf-margin and are accompanied almost from the first by minute roots.

Pin up a bryophyllum leaf on the wall of the room or lay it on the surface of moist earth, and follow, day by day, the formation and development of the buds which it may produce.

This plant seems to rely largely upon leaf-budding to reproduce itself, for in a moderately cool climate it rarely flowers or seeds, but drops its living leaves freely, and from each such leaf one or several new plants may be produced.

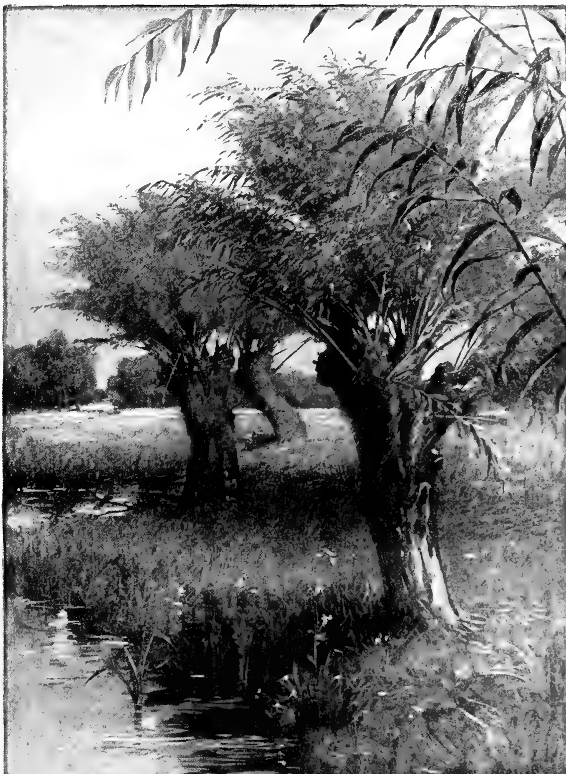


Plate II. — Pollarded Willows

140. Review Summary of Chapter VIII.

- Buds
  - Coverings . . . .
  - Contents . .
    - leaf-buds . . . .
    - flower-buds . . . .
    - mixed buds . . . .

- Classes of buds as regards position . .
  - regular
  - irregular . . . .

Make a sketch of Fig. 82 as it looked in June of the same summer; also as it would look the following June. Sketch the twigs of Fig. 30 and Fig. 86 as seen one year later.

CHAPTER IX

LEAVES

141. The Elm Leaf. — Sketch the leafy twig of elm that is supplied to you.[1]

Report on the following points:

(*a*) How many rows of leaves?

(*b*) How much overlapping of leaves when the twig is held with the upper sides of the leaves toward you? Can you suggest a reason for this? Are the spaces between the edges of the leaves large or small compared with the leaves themselves?

Pull off a single leaf and make a very careful sketch of its under surface, about natural size. Label the broad expanded part the *blade*, and the stalk by which it is attached to the twig, *leaf-stalk* or *petiole.*

Study the outline of the leaf and answer these questions:

(*a*) What is the shape of the leaf taken as a whole? (See Fig. 88.) Is the leaf *bilaterally symmetrical*, *i.e.*, is there a middle line running through it lengthwise, along which it could be so folded that the two sides would precisely coincide?

(*b*) What is the shape of the tip of the leaf? (See Fig. 89.)

(*c*) Shape of the base of the leaf? (See Fig. 90.)

(*d*) Outline of the margin of the leaf? (See Fig. 93.)

Notice that the leaf is traversed lengthwise by a strong *midrib* and that many so-called *veins* run from this to the margin. Are

[1] Any elm will answer the purpose. Young strong shoots which extend horizontally are best, since in these leaves are most fully developed and their distribution along the twig appears most clearly. Other good kinds of leaves with which to begin the study, if elm leaves are not available, are those of beech, oak, willow, peach, cherry, apple. Most of the statements and directions above given would apply to any of the leaves just enumerated. If this chapter is reached too early in the season to admit of suitable material being procured for the study of leaf arrangement, that topic may be omitted until the leaves of forest trees have sufficiently matured.

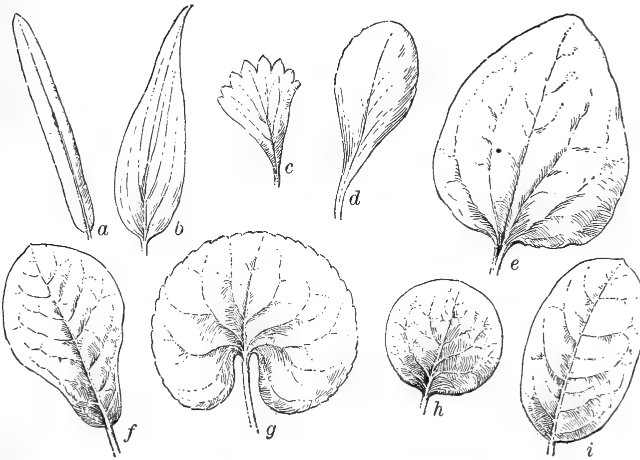


FIG. 88. — General Outline of Leaves.

a, linear; *b*, lanceolate; *c*, wedge-shaped; *d*, spatulate; *e*, ovate; *f*, obovate; *g*, kidney-shaped; *h*, orbicular; *i*, elliptical.

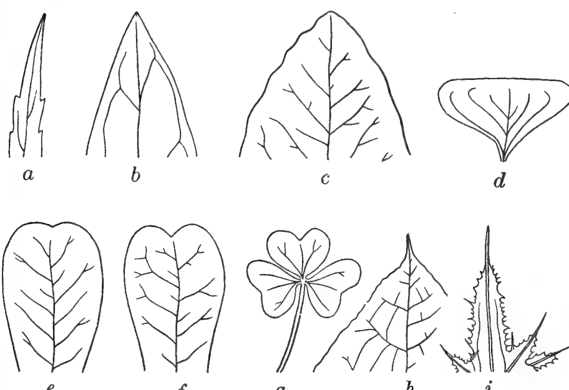


FIG. 89. — Tips of Leaves.

a, acuminate or taper-pointed; *b*, acute; *c*, obtuse; *d*, truncate; *e*, retuse; *f*, emarginate or notched; *g* (end leaflet), obcordate; *h*, cuspidate, — the point sharp and rigid; *i*, mucronate, — the point merely a prolongation of the midrib.

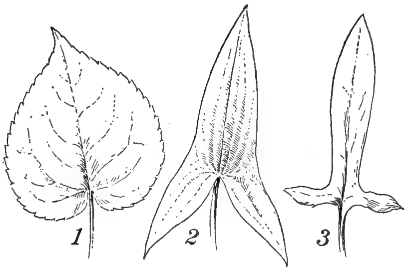


FIG. 90. — Shapes of Bases of Leaves.

1, heart-shaped (unsymmetrically); 2, arrow-shaped; 3, halberd-shaped.

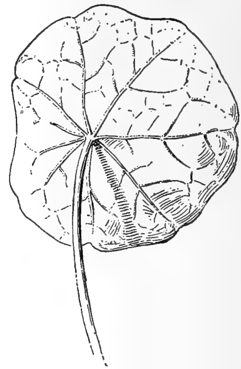


FIG. 91. — Peltate Leaf of Tropæolum.

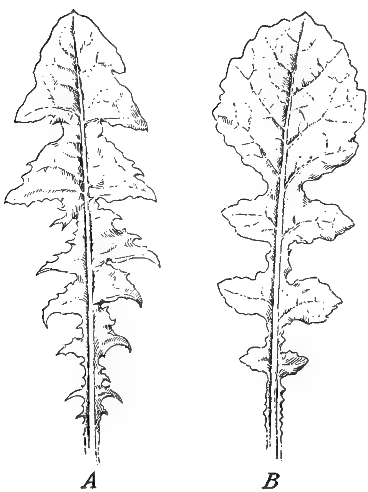


FIG. 92.

A, runcinate leaf of dandelion; *B*, lyrate leaf.

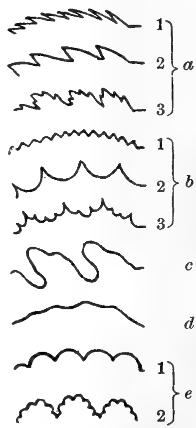


FIG. 93. — Shapes of Margins of Leaves.

a (1), finely serrate; (2), coarsely serrate; (3), doubly serrate. *b* (1), finely dentate; (2), sinuate dentate; (3), doubly dentate. *c*, deeply sinuate. *d*, wavy. *e* (1), crenate or scalloped; (2), doubly crenate.

these veins parallel? Hold the leaf up towards the light and see how the main veins are connected by smaller *veinlets.* Examine with your glass the leaf as held to the light and make a careful sketch of portions of one or two veins and the intersecting veinlets. How is the course of the veins shown on the upper surface of the leaf?

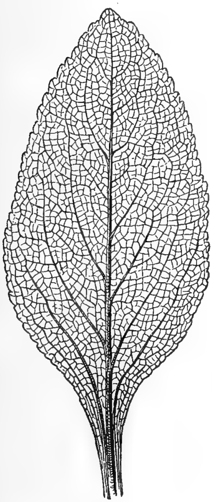


FIG. 94.—Netted Veining (pinnate) in the Leaf of the Foxglove.

Examine both surfaces of the leaf with the glass and look for hairs distributed on the surfaces. Describe the manner in which the hairs are arranged.

The various forms of leaves are classed and described by botanists with great minuteness,[1] not simply for the study of leaves themselves, but also because in classifying and describing plants the characteristic forms of the leaves of many kinds of plants form a very simple and ready means of distinguishing them from each other and identifying them. The student is not expected to learn the names of the several shapes of leaves as a whole or of their bases, tips, or margins, except in those cases in which he needs to use and apply them.

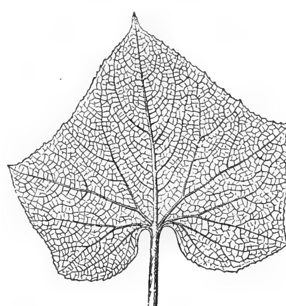


FIG. 95.—Netted Veining (palmate) in Leaf of Melon.

Many of the words used to describe the shapes of leaves are equally applicable to the leaf-like parts of flowers.

[1] See Kerner and Oliver's *Natural History of Plants,* Vol. I, pp. 623–637.

142. The Maple Leaf. — Sketch the leafy twig.

Are the leaves arranged in rows like those of the elm? How are they arranged?

How are the petioles distorted from their natural positions to bring the proper surface of the leaf upward toward the light?

Do the edges of these leaves show larger spaces between them than the elm leaves did, *i.e.*, would a spray of maple intercept the sunlight more or less perfectly than a spray of elm? Pull off a single leaf and sketch its lower surface, about natural size.

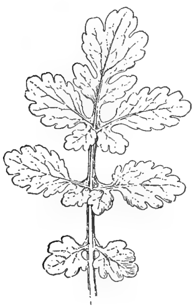


FIG. 96.—Pinnately Divided Leaf of Celandine.

The blade of the leaf is discontinuous, consisting of several portions between which are spaces in which one part of the blade has been developed.

Of the two main parts whose names have already been learned (blade and petiole), which is more developed in the maple than in the elm leaf?

Describe:

(*a*) The shape of the maple leaf as a whole. To settle this, place the leaf on paper, mark the positions of the extreme points and connect these by a smooth line.

(*b*) Its outline as to main divisions: of what kind and how many.

(*c*) The detailed outline of the margin (Fig. 93).

Compare the mode of veining or venation of the elm and the maple leaf by making a diagram of each.

These leaves agree in being *netted-veined; i.e.*, in having veinlets that join each other at many angles, so as to form a sort of delicate lace-work, like Figs. 94 and 95.

They differ, however, in the arrangement of the principal veins. Such a leaf as that of the elm is said to be feather-veined, or *pinnately veined.*

The maple leaf, or any leaf with closely similar venation, is said to be *palmately veined.* Describe the difference between the two plans of venation.

143. Relation of Venation to Shape of Leaves. — As soon as the student begins to observe leaves somewhat widely,

he can hardly fail to notice that there is a general relation between the plan of venation and the shape of the leaf. How may this relation be stated? In most cases the principal veins follow at the outset a pretty straight course, a fact for which the student ought to be able to give a reason after he has performed Exp. XXXII.

On the whole, the arrangement of the veins seems to be such as to stiffen the leaf most in the parts that need most support, and to reach the region near the margin by as short a course as possible from the end of the petiole.

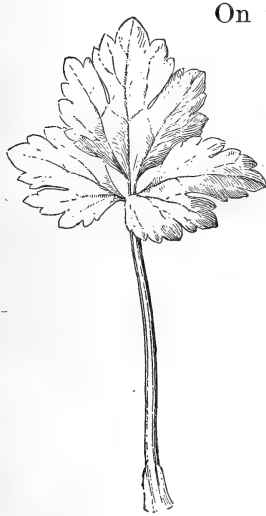


FIG. 97. — Palmately Divided Leaf of Buttercup.

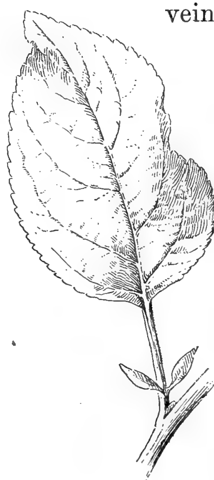


FIG. 98. — Leaf of Apple, with Stipules.

FIG. 99. — Leaf of Pansy, with Leaf-Like Stipules.

144. Stipules. — Although they are absent from many leaves, and disappear early from others, *stipules* form a part of what the botanist regards as an ideal or model leaf.[1] When present they are sometimes found as little

[1] Unless the elm twigs used in the previous study were cut soon after the unfolding of the leaves in spring, the stipules may not have been left in any recognizable shape.

bristle-shaped objects at the base of the leaf, as in the apple leaf (Fig. 98), sometimes as leaf-like bodies, for example in the pansy (Fig. 99), and in many other forms, one of which is that of spinous appendages, as shown in the common locust (Fig. 103).

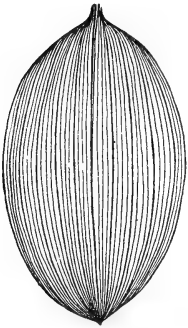


FIG. 100. — Parallel-Veined Leaf of Solomon's Seal.

145. Parallel-Veined Leaves. — The leaves of many great groups of plants, such as the lilies, the sedges, and the grasses, are commonly *parallel-veined*, that is, with the veins running nearly parallel, lengthwise through the blade, as shown in Fig. 100, or with parallel veins proceeding from a midrib and thence extending to the margin, as shown in Fig. 101.

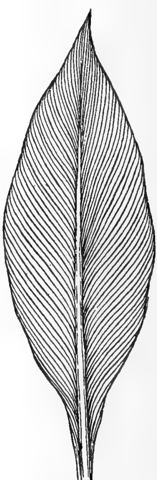


FIG. 101. — Parallel Veining in Canna. Veins running from midrib to margin.

146. Occurrence of Netted Veining and of Parallel Veining. — The student has already, in his experiments on germination, had an opportunity to observe the difference in mode of veining between the leaves of some dicotyledonous plants and those of monocotyledonous plants. This difference is general throughout these great groups of flowering plants. What is the difference?

The polycotyledonous pines, spruces, and other coniferous trees have leaves with but a single vein, or two or three parallel ones, but in their case the veining could hardly be other than parallel, since the needle-like leaves are so

narrow that no veins of any considerable length could exist except in a position lengthwise of the leaf.

The fact that a certain plan of venation is found mainly in plants with a particular mode of germination, of stem structure, and of arrangement of floral parts, is but one of the frequent cases in botany in which the structures of plants are correlated in a way which it is not easy to explain.

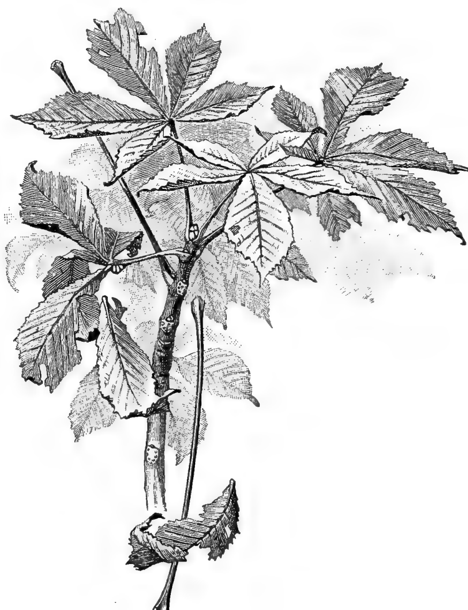


FIG. 102. — The Fall of the Horse-Chestnut Leaf.

No one knows why plants with two cotyledons should have netted-veined leaves, but many such facts as this are familiar to every botanist.

147. Simple and Compound Leaves. — The leaves so far studied are *simple leaves*, that is, leaves of which the blades are more or less entirely united into one piece. But while in the elm the margin is cut in only a little way, in some maples it is deeply cut in toward the bases of the veins. In some leaves the gaps between the adjacent portions extend all the way down to the petiole

(in palmately veined leaves) or to the midrib (in pinnately veined ones). Such divided leaves are shown in Figs. 96 and 97.

In still other leaves, known as *compound leaves*, the petiole, as shown in Fig. 102 (*palmately compound*), or the midrib, as shown in Fig. 103 (*pinnately compound*), bears what look to be separate leaves. These differ in their nature and mode of origin from the portions of the blade of a divided leaf. One result of this difference appears in the fact that some time before the whole leaf is ready to fall from the tree or other plant in autumn, the separate portions or leaflets of a compound leaf are seen to be jointed at their attachments, just as whole leaves are to the part of the stem from which they grow. In Fig. 102 the horse-chestnut leaf is shown at the time of falling, with some of the leaflets already disjointed.

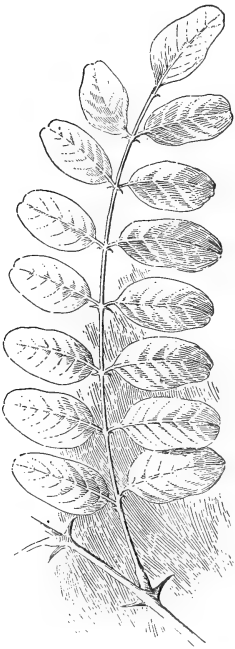


FIG. 103. — Pinnately Compound Leaf of Locust, with Spines for Stipules.

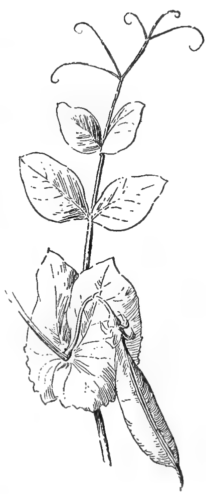


FIG. 104. — Pinnately Compound Leaf of Pea. A tendril takes the place of a terminal leaflet.

That a compound leaf, in spite of the joints of the

separate leaflets, is really only one leaf is shown: (1) by the absence of buds in the axils of leaflets (see Fig. 82); (2) by the arrangement of the blades of the leaflets horizontally, without any twist in their individual leaf-stalks; (3) by the fact that their arrangement on the midrib does not follow any of the systems of leaf arrangement on the stem (Sect. 149). If each leaflet of a compound leaf should itself become compound, the result would be to produce a *twice compound* leaf. Fig. 113 shows that of an acacia. What would be the appearance of a thrice compound leaf?

148. Review Summary of Leaves.[1]

Parts of a model leaf	1. 2. 3.
Classes of netted-veined leaves	1. 2.
Classes of parallel-veined leaves	1. 2.
Relation of venation to number of cotyledons	
Compound leaves; — types, dependent on arrangement of leaflets	1. 2.
Once, twice, or three times compound	

[1] Illustrate by sketches if possible.

CHAPTER X

LEAF ARRANGEMENT FOR EXPOSURE TO SUN AND AIR; MOVEMENTS OF LEAVES AND SHOOTS

149. Leaf Arrangement.[1] — As has been learned from the study of the leafy twigs examined, leaves are quite generally arranged so as to secure the best possible exposure to the sun and air. This, in the vertical shoots of the elm, the oak (Fig. 105), the apple, beech, and other alternate-leaved trees, is not inconsistent with their spiral arrangement of the leaves around the stem. In horizontal twigs and branches of the elm, the beech (Fig. 106), the chestnut, the linden, and many other trees and shrubs, the desired effect is secured by the arrangement of all the leaves in two flat rows, one on each side of the twig.

FIG. 105. — Leaf Arrangement of the Oak.

FIG. 106. — Leaf Arrangement of European Beech.

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. I, pp. 396–424.

PLATE III. — Exposure to Sunlight, Japanese Ivy

The rows are produced, as it is easy to see on examining such a leafy twig, by a twisting about of the petioles. The adjustment in many opposite-leaved trees and shrubs consists in having each pair of leaves cover the spaces between the pair below it, and sometimes in the lengthening of the lower petioles so as to bring the blades of the lower leaves outside those of the upper leaves. Examination of Figs. 107 and 108 will make the matter clear.

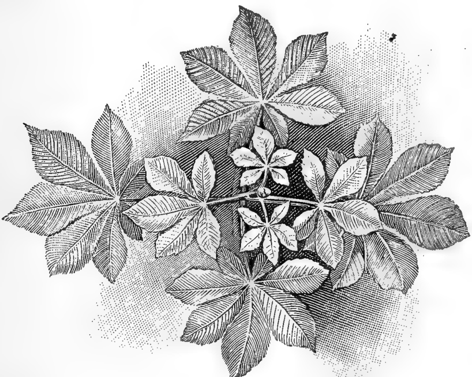


Fig. 107.—Leaf Arrangement of Horse-Chestnut on Vertical Shoots (top view).

The student should not fail to study the leafage of several trees of different kinds on the growing tree itself, and in climbers on walls (Plate III), and to notice how circumstances modify the position of the leaves. Maple leaves, for example, on the ends of the branches are arranged much

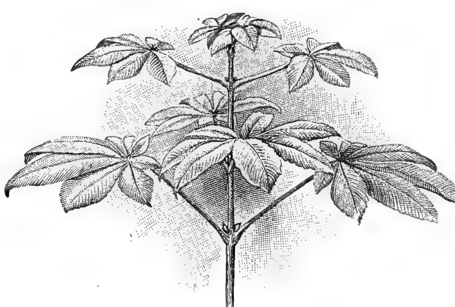


Fig. 108.—Leaf Arrangement of Horse-Chestnut on Vertical Shoots (side view).

like those of the horse-chestnut, but they are found to be arranged more nearly flatwise along the inner portions of the branches, that is, the portions nearer the tree. Figs. 109 and 110 show the remarkable difference in arrangement in different branches of the Deutzia, and equally interesting modifications may be found in alternate-leaved trees, such as the elm and the cherry.

FIG. 109. — Opposite Leaves of Deutzia[1] (from the same shrub as Fig. 110), as arranged on a Horizontal Branch.

150. Leaf-Mosaics. — In very many cases the leaves at the end of a shoot are so arranged as to form a pretty symmetrical pattern, as in the horse-chestnut (Fig. 107). When this is sufficiently regular, usually with the space between the leaves a good deal smaller than the areas of the leaves themselves, it is called a *leaf-mosaic* (Fig. 111). Many of the most interesting leaf-groups of this sort (as

[1] *Deutzia crenata.*

in the figure above mentioned) are found in the so-called root-leaves of plants. Good examples of these are the dandelion, chicory, fall dandelion, thistle, hawkweed, pyrola, plantain. How are the leaves of these plants kept from shading each other?

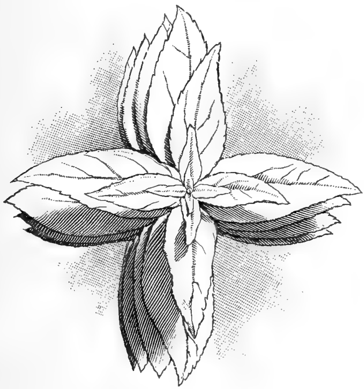


FIG. 110.—Opposite Leaves of Deutzia, as arranged on a Vertical Branch.

151. Much-Divided Leaves. — Not infrequently leaves are cut into slender fringe-like divisions, as in the carrot, tansy, southernwood, wormwood, yarrow, dog-fennel, cypress-vine, and many other common plants. This kind of leaf seems to be adapted to offer considerable surface to the sun without cutting off too much light from other leaves underneath. Such a leaf is in much less danger of being torn by severe winds than are broader ones with undivided margins. The same purposes are served by compound leaves with very many small leaflets, such as those of the honey-locust, mimosa acacia (Fig. 113), and other trees and shrubs of the pea family. What kind of shade is produced by a horse-chestnut or a maple tree compared with that of a honey-locust or an acacia?

FIG. 111.—Leaf-Mosaic of a Campanula.

152. Daily Movements of Leaves. — Many compound leaves have the power of changing the position of their leaflets to accommodate themselves to varying conditions of light and temperature. Some plants have the power of directing the leaves or leaflets edgewise towards the sun during the hottest parts of the day, allowing them to extend their surfaces more nearly in a horizontal direction during the cooler hours.

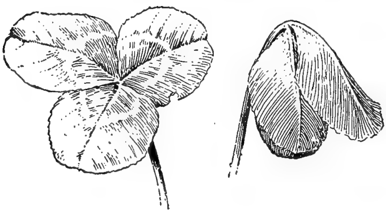


FIG. 112. — A Leaf of Red Clover. At the left, leaf by day; at the right, the same leaf asleep at night.

The so-called "sleep" of plants has long been known, but this subject has been most carefully studied rather recently. The wood sorrel, or oxalis, the common bean, clovers, and the locust tree are some of the most familiar of the plants whose leaves assume decidedly different positions at night from those which they occupy during the day. Sometimes the leaflets rise at night, and in many instances they droop, as in the red clover (Fig. 112) and the acacia (Fig. 113). One useful purpose, at any rate, that is served by the leaf's taking the nocturnal position is protection from frost. It has been proved experimentally that when part of the leaves on a plant are prevented from assuming the folded position, while others are allowed to do so, and the plant is then exposed during a frosty night, the folded ones may escape while the others are killed. Since many plants in tropical climates fold their leaves at night, it is certain that this movement has other purposes than protection from frost, and probably there is

much yet to be learned about the meaning and importance of leaf-movements.

153. Cause of Sleep-Movements. — The student may very naturally inquire whether the change to the nocturnal position is brought about by the change from light to darkness or whether it depends rather upon the time of day. It will be interesting to try an experiment in regard to this.

EXPERIMENT XXVI

Remove a pot containing an oxalis from a sunny window to a dark closet, at about the same temperature, and note at intervals of five minutes the condition of its leaves for half an hour or more.

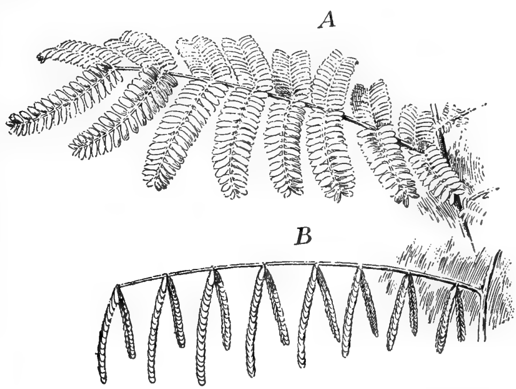


FIG. 113.—A Leaf of Acacia.
A, as seen by day; *B*, the same leaf asleep at night.

154. Structure of the Parts which cause Leaf-Motions. — In a great number of cases the daily movements of leaves are produced by special organs at the bases of the leaf-stalks. These cushion-like organs, called *pulvini* (Fig. 114), are composed mainly of parenchymatous tissue

(Sect. 106), which contains much water. It is impossible fully to explain in simple language the way in which the cells of the pulvini act, but in a general way it may be said that changes in the light to which the plant is exposed cause rather prompt changes in the amount of water in the cells in one portion or other of the pulvinus. If the cells on one side are filled fuller of water than usual, that side of the pulvinus will be expanded and make the leaf-stalk bend toward the opposite side. The promptness of these movements is no doubt in considerable measure due to the fact that in the pulvini (as in many other parts of plants) the protoplasm of adjacent cells is connected. Delicate threads of protoplasm extend through the cell-walls, making the whole tissue a living web, so that any suitable stimulus or excitant which acts on one part of the organ will soon affect the whole organ.

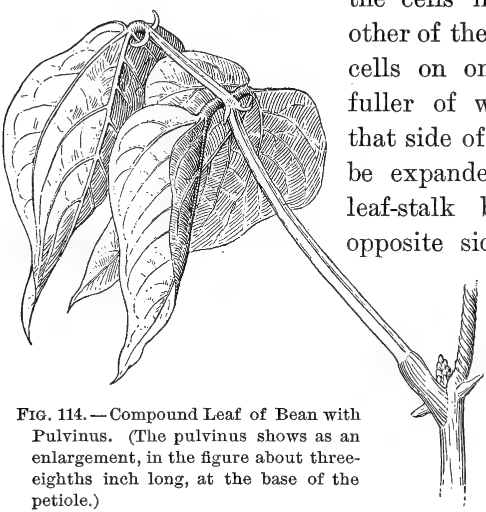
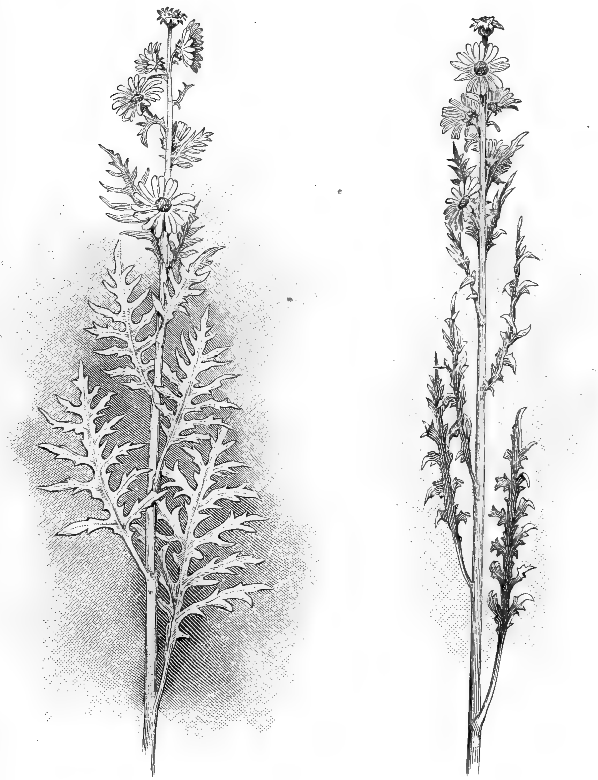


FIG. 114. — Compound Leaf of Bean with Pulvinus. (The pulvinus shows as an enlargement, in the figure about three-eighths inch long, at the base of the petiole.)

155. Vertically Placed Leaves. — Very many leaves, like those of the iris (Fig. 44), always keep their principal surfaces nearly vertical, thus receiving the morning and evening sun upon their faces, and the noonday sun (which is so intense as to injure them when received full on the

surface) upon their edges. This adjustment is most perfect in the compass-plant of the prairies of the Mississippi basin. Its leaves stand very nearly upright, many with



A B

FIG. 115.—Leaves standing nearly Vertical in Compass-Plant (*Silphium laciniatum*). *A*, view from east or west; *B*, from north or south.

their edges just about north and south (Fig. 115), so that the rays of the midsummer sun will, during every bright

day, strike the leaf-surfaces nearly at right angles during a considerable portion of the forenoon and afternoon, while at midday only the edge of each leaf is exposed to the sun.

156. Movements of Leaves and Stems toward or away from Light (Heliotropic Movements). — The student doubtless learned from his experiments with seedling plants that their stems tend to seek light. The whole plant above ground usually bends toward the quarter from which the strongest light comes. Such movements are called *heliotropic* from two Greek words which mean turning toward the sun. How do the plants in a window behave with reference to the light?

EXPERIMENT XXVII

How do Young Shoots of English Ivy bend with Reference to Light? — Place a thrifty potted plant of English ivy before a small window, *e.g.*, an ordinary cellar window, or in a large covered box, painted dull black within and open only on the side toward a south window. After some weeks note the position of the tips of the shoots. Explain the use of their movements to the plant.

157. Positive and Negative Heliotropic Movements; how produced. — Plants may bend either toward or away from the strongest light. In the former case they are said to show *positive heliotropism*, in the latter *negative heliotropism.* In both cases the movement is produced by unequal growth, brought about by the unequal lighting of different sides of the stem. If the less strongly lighted side grows faster, what kind of heliotropism results? If the more strongly lighted side grows faster, what kind of heliotropism results? How would a plant behave if placed on a

revolving table before a window and slowly turned during the hours of daylight?

158. Review Summary of Chapter X.

Leaf arrangement . . .	For vertical twigs	
	For horizontal twigs . . .	
Movements of leaves . .	Apparatus for	
	Causes of	
	Uses of	
Compass-plants		
Heliotropic bending of stems	Positive	
	Negative	

CHAPTER XI

MINUTE STRUCTURE OF LEAVES; FUNCTIONS OF LEAVES

159. Leaf of Lily. — A good kind of leaf with which to begin the study of the microscopical structure of leaves in general is that of the lily.[1]

160. Cross-Section of Lily Leaf. — The student should first examine with the microscope a cross-section of the leaf, that is, a very thin slice, taken at right angles to the upper and under surfaces and to the veins. This will show:

(*a*) The upper epidermis of the leaf, a thin, nearly transparent membrane.

(*b*) The intermediate tissues.

(*c*) The lower epidermis.

Use a power of from 100 to 200 diameters. In order to ascertain the relations of the parts, and to get their names, consult Fig. 116. Your section is by no means exactly like the figure; sketch it. Label properly all the parts shown in your sketch.

Are any differences noticeable between the upper and the lower epidermis? Between the layers of cells immediately adjacent to each?

161. Under Surface of Lily Leaf. — Examine with a power of 200 or more diameters the outer surface of a piece of epidermis from the lower side of the leaf.[2] Sketch carefully, comparing your sketch with Figs. 117 and 118, and labeling it to agree with those figures.

Examine another piece from the upper surface; sketch it.

How does the number of *stomata* in the two cases compare?

[1] Any kind of lily will answer.

[2] The epidermis may be started with a sharp knife, then peeled off with small forceps, and mounted in water for microscopical examination.

Take measurements from the last three sketches with a scale and, knowing what magnifying power was used, answer these questions[1]:

(*a*) How thick is the epidermis?

(*b*) What is the length and the breadth of the epidermal cells?

(*c*) What is the average size of the pulp-cells?

A *stoma* is a microscopic pore or slit in the epidermis. It is bounded and opened and shut by guard-cells (Fig. 118, *g*), usually two in number. These are generally

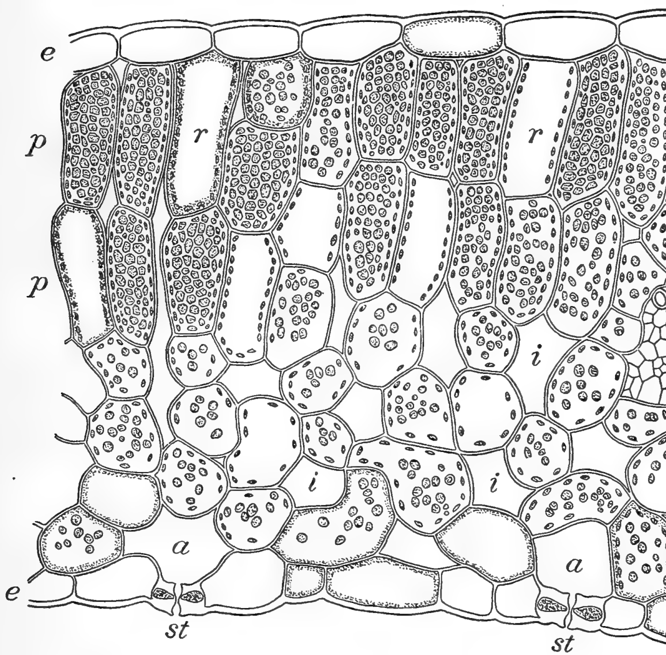


FIG. 116. — Vertical Section of the Leaf of the Beet. (Much magnified.)

e, epidermis; *p*, palisade-cells (and similar elongated cells); *r*, cells filled with red cell sap; *i*, intercellular spaces; *a*, air spaces communicating with the stomata; *st*, stomata, or breathing pores.

[1] The teacher may measure the size with the *camera lucida*.

somewhat kidney-shaped and become more or less curved as they are fuller or less full of water (see Sect. 170).

162. Calculation of Number of Stomata per Unit of Area. — In order to get a fairly exact idea of the number of stomata on a unit of leaf-surface, the most convenient plan is to make use of a photomicrograph. The bromide enlargement No. 12 of the Tower series represents about a twenty-five-hundredth of a square inch of the lower epidermis of the cyclamen leaf, magnified until it is about fifteen inches square. Count the number of stomata on the entire photograph, then calculate the number of stomata on a square inch of the surface of this leaf. If a cyclamen plant has twelve leaves, each with an average area of six square inches, calculate the number of stomata of the lower epidermis of all the leaves taken together.

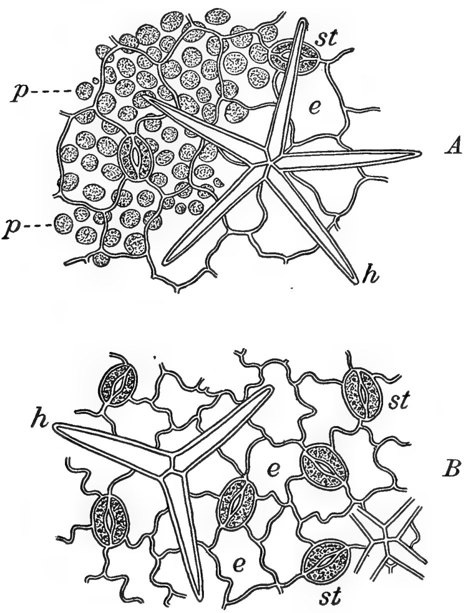


FIG. 117. — Epidermis of Leaf of Althæa. (Much magnified.)

A, from upper surface; *B*, from lower surface. *h*, star-shaped compound hairs; *st*, stomata; *p*, upper ends of palisade-cells, seen through the epidermis; *e*, cells of epidermis.

In the case of an apple tree, where the epidermis of the lower surface of the leaf contains about 24,000 stomata to the square inch, or the black walnut, with nearly 300,000 to the square inch, the total number on a tree is inconceivably large.

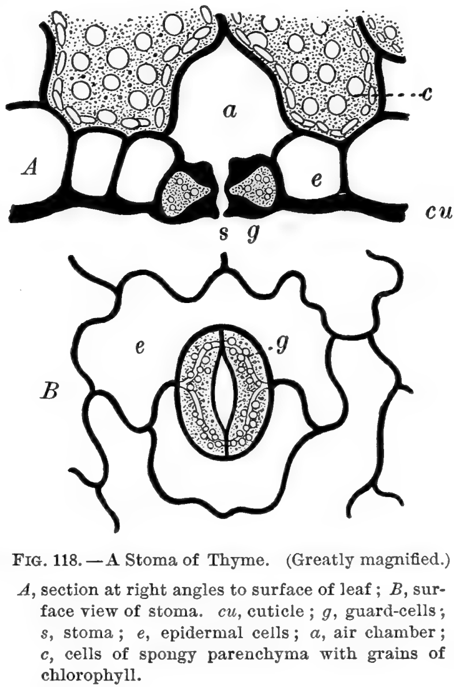


FIG. 118.—A Stoma of Thyme. (Greatly magnified.)

A, section at right angles to surface of leaf; *B*, surface view of stoma. *cu*, cuticle; *g*, guard-cells; *s*, stoma; *e*, epidermal cells; *a*, air chamber; *c*, cells of spongy parenchyma with grains of chlorophyll.

163. Uses of the Parts examined.—It will be most convenient to discuss the uses of the parts of the leaf a little later, but it will make matters simpler to state at once that the epidermis serves as a mechanical protection to the parts beneath and prevents excessive evaporation, that the palisade-cells (which it may not be easy to make out very clearly in a roughly prepared section) hold large quantities of the green coloring matter of the leaf in a position where it can receive enough but not too much sunlight, and the cells of the spongy parenchyma share the work of the palisade-cells, besides evaporating much water. The stomata admit air to the interior of the leaf (where the air spaces

serve to store and to distribute it), they allow oxygen and carbonic acid gas to escape, and, above all, they regulate the evaporation of water from the plant.

164. Leaf of "India-Rubber Plant."[1] — Study with the microscope, as the lily leaf was studied, make the same set of sketches, note the differences in structure between the two leaves, and try to discover their meaning.

How does the epidermis of the two leaves compare?

Which has the larger stomata?

Which would better withstand great heat and long drought?

165. Chlorophyll as found in the Leaf. — Slice off a little of the epidermis from some such soft, pulpy leaf as

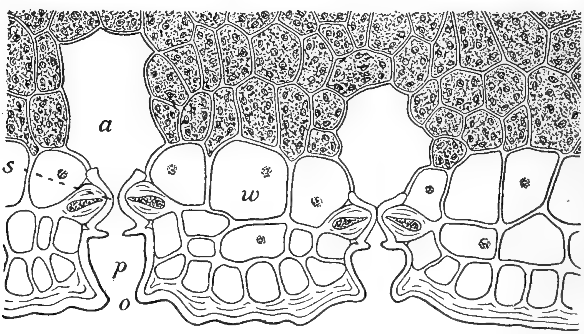


FIG. 119. — Section through Lower Epidermis of Leaf of India-Rubber Plant (*Ficus elastica*). (Magnified 330 diameters.)

o, opening of pit; *p*, pit leading to stoma; *s*, stoma, with two guard-cells; *w*, water-storage cells of epidermis; *a*, an air space; around and above the air spaces are cells of the spongy parenchyma.

that of the common field sorrel,[2] live-for-ever, or spinach; scrape from the exposed portion a very little of the green pulp; examine with the highest power attainable with your microscope, and sketch several cells.

[1] *Ficus elastica*, a kind of fig tree.

[2] *Rumex Acetosella.*

Notice that the green coloring matter is not uniformly distributed, but that it is collected into little particles called *chlorophyll bodies* (Fig. 120, *p*).

166. Woody Tissue in Leaves. — The veins of leaves consist of fibro-vascular bundles containing wood and vessels much like those of the stem of the plant. Indeed, these bundles in the leaf are continuous with those of the stem, and consist merely of portions of the latter, looking as if unraveled, which pass outward and upward from the stem into the leaf under the name of *leaf-traces*. These traverse the petiole often in a somewhat irregular fashion.

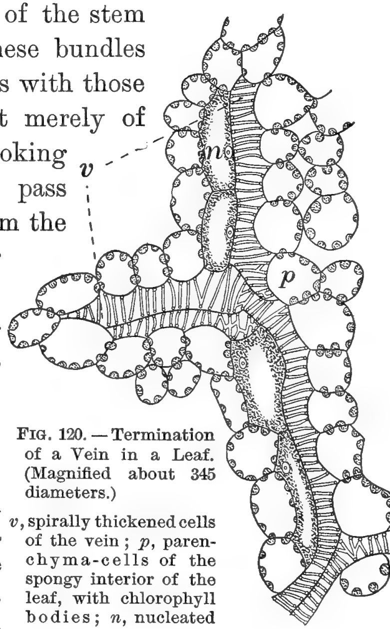


FIG. 120. — Termination of a Vein in a Leaf. (Magnified about 345 diameters.)

v, spirally thickened cells of the vein; *p*, parenchyma-cells of the spongy interior of the leaf, with chlorophyll bodies; *n*, nucleated cells.

EXPERIMENT XXVIII

Passage of Water from Stem to Leaf. — Place a freshly cut leafy shoot of some plant with large thin leaves, such as *Hydrangea hortensia*, in eosin solution for a few minutes. As soon as the leaves show a decided reddening, pull some of them off and sketch the red stains on the scars thus made. What does this show?

167. Experimental Study of Functions of Leaves. — The most interesting and profitable way in which to find out what work leaves do for the plant is by experimenting upon them. Much that relates to the uses of leaves is

not readily shown in ordinary class-room experiments, but some things can readily be demonstrated in the experiments which follow.

EXPERIMENT XXIX

Transpiration. — Take two twigs or leafy shoots of any thin-leafed plant;[1] cover the cut end of each stem with a bit of grafting wax[2] to prevent evaporation from the cut surface. Put one shoot into a fruit jar, screw the top on, and leave in a warm room; put the other beside it, and allow both to remain some hours. Examine the relative appearance of the two, as regards wilting, at the end of the time.

Which shoot has lost most? Why? Has the one in the fruit jar lost any water? To answer this question, put the jar (without opening it) into a refrigerator; or, if the weather is cold, put it out of doors for a few minutes, and examine the appearance of the inside of the jar. What does this show?[3]

168. Uses of the Epidermis.[4] — The epidermis, by its toughness, tends to prevent mechanical injuries to the leaf, and after the filling up of a part of its outer portion with a corky substance it greatly diminishes the loss of water from the general surface. This process of becoming filled with cork substance, *suberin* (or a substance of similar properties known as *cutin*) is essential to the safety of leaves or of young stems which have to withstand heat and dryness. The corky or cutinized cell-wall is waterproof, while ordinary cellulose allows water

[1] Hydrangea, squash, melon, or cucumber is best; many other kinds will answer very well.

[2] Grafting wax may be bought of nurserymen or seedsmen.

[3] If the student is in doubt whether the jar filled with ordinary air might not behave in the same way, the question may be readily answered by putting a sealed jar of air into the refrigerator.

[4] See Kerner and Oliver's *Natural History of Plants*, Vol. I, pp. 273–362.

to soak through it with ease. Merely examining sections of the various kinds of epidermis will not give nearly as good an idea of their properties as can be obtained by studying the behavior during severe droughts of plants which have strongly cutinized surfaces and of those which have not. Fig. 121, however, may convey some notion of the difference between the two kinds of structure. In most cases, as in the india-rubber tree, the external epidermal cells (and often two or three layers of cells beneath these) are filled with water, and thus serve as reservoirs from which the outer parts of the leaf and the stem are at times supplied.

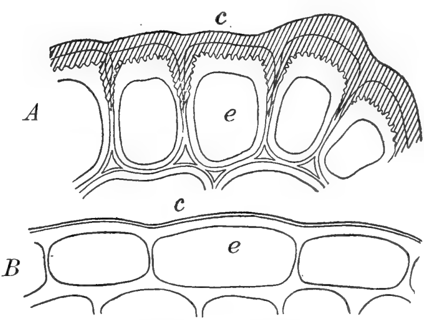


FIG. 121. — Unequal Development of Cuticle by Epidermis-Cells.

A, epidermis of Butcher's Broom (*Ruscus*); *B*, epidermis of sunflower; *c*, cuticle; *e*, epidermis-cells.

In many cases, noticeably in the cabbage, the epidermis is covered with a waxy coating, which doubtless increases the power of the leaf to retain needed moisture, and which certainly prevents rain or dew from covering the leaf-surfaces, especially the lower surfaces, so as to hinder the operation of the stomata. Many common plants, like the meadow rue and the nasturtium, possess this power to shed water to such a degree that the under surface of the leaf is hardly wet at all when immersed in water. The air-bubbles on such leaves give them a silvery appearance when held under water.

169. Hairs on Leaves. — Many kinds of leaves are more or less hairy or downy, as those of the mullein, the "mullein pink," many cinquefoils, and other common plants. In some instances this hairiness may be a protection against snails or other small leaf-eating animals, but in other cases it seems to be pretty clear that the woolliness (so often confined to the under surface) is to lessen the loss of water through the stomata. The Labrador tea is an excellent example of a plant, with a densely woolly coating on the lower surface of the leaf. The leaves, too, are partly rolled up (see Fig. 224), with the upper surface outward, so as to give the lower surface a sort of deeply grooved form, and on the lower surface all of the stomata are placed. This plant, like some others with the same characteristics, ranges far north into regions where the temperature, even during summer, often falls so low that absorption of water by the roots ceases, since it has been shown that this nearly stops a little above the freezing point of water (see Exp. XVII). Exposed to cold, dry winds, the plant would then often be killed by complete drying if it were not for the protection afforded by the woolly, channeled under surfaces of the leaves.[1]

170. Operation of the Stomata. — The stomata serve to admit air to the interior of the leaf, and to allow moisture, in the form of vapor, to pass out of it. They do this not in a passive way, as so many mere holes in the epidermis might, but to a considerable extent they regulate the rapidity of transpiration, opening more widely in damp weather and closing in dry weather. The opening is

[1] This adaptation is sufficiently interesting for class study.

Plate IV. — A Cypress Swamp

caused by each of the guard-cells bending into a more kidney-like form than usual, and the closing by a straightening out of the guard-cells. The under side of the leaf, free from palisade-cells, abounding in intercellular spaces, and pretty well protected from becoming covered with rain or dew, is especially adapted for the working of the stomata, and accordingly we usually find them in much greater numbers on the lower surface. On the other hand, the little flowerless plants known as liverworts, which lie prostrate on the ground, have their stomata on the upper surface, and so do the leaves of pond lilies, which lie flat on the water. In those leaves which stand with their edges nearly vertical, the stomata are distributed somewhat equally on both surfaces. Stomata occur in the epidermis of young stems, being replaced later by the lenticels. Those plants which, like the cacti, have no ordinary leaves, transpire through the stomata scattered over their general surfaces.

The health of the plant depends largely on the proper working condition of the stomata, and one reason why plants in cities often fail to thrive is that the stomata become choked with dust and soot. In some plants, as the oleander, provision is made for the exclusion of dust by a fringe of hairs about the opening of each stoma. If the stomata were to become filled with water, their activity would cease until they were freed from it; hence many plants have their leaves, especially the under surfaces, protected by a coating of wax which sheds water.

171. Measurement of Transpiration. — We have already proved that water is lost by the leaves, but it is worth while to perform a careful experiment to reduce our

knowledge to an exact form, to learn how much water a given plant transpires under certain conditions. It is also desirable to find out whether different kinds of plants transpire alike, and what changes in the temperature, the dampness of the air, the brightness of the light, to which a plant is exposed, have to do with its transpiration. Another experiment will show whether both sides of a leaf transpire alike.

EXPERIMENT XXX

Amount of Water lost by Transpiration. — Procure a thrifty hydrangea[1] and a small "india-rubber plant,"[2] each growing in a small flower-pot, and with the number of square inches of leaf-surface in the two plants not too widely different. Calculate the area of the leaf-surface for each plant, by dividing the surface of a piece of tracing cloth into a series of squares one-half inch on a side, holding an average leaf of each plant against this and counting the number of squares and parts of squares covered by the leaf. Or weigh a square inch of tinfoil on a very delicate balance, cut out a piece of the same kind of tinfoil of the size of an average leaf, weigh this and calculate the leaf-area from the two weights.

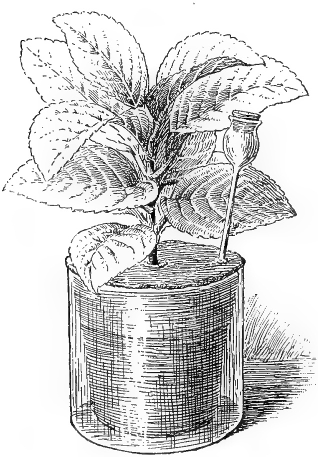


FIG. 122. — A Hydrangea potted in a Battery Jar for Exp. XXX.

This area, multiplied by the number of leaves for each plant, will give approximately the total evaporating surface for each.

Transfer each plant to a glass battery jar of suitable size. Cover

[1] The common species of the greenhouses, *Hydrangea Hortensia*.
[2] This is really a fig, *Ficus elastica*.

the jar with a piece of sheet lead, slit to admit the stem of the plant, invert the jar and seal the lead to the glass with a hot mixture of beeswax and rosin. Seal up the slit and the opening about the stem with grafting wax. A thistle-tube, such as is used by chemists, is also to be inserted, as shown in Fig. 122.[1] The mouth of this may be kept corked when the tube is not in use for watering.

Water each plant moderately and weigh the plants separately on a balance that is sensitive to one-fifth gram. Record the weights, allow the plants to stand in a sunny, warm room for twenty-four hours and reweigh.

Add to each plant just the amount of water which is lost,[2] and continue the experiment in the same manner for several days so as to ascertain, if possible, the effect upon transpiration of varying amounts of water in the atmosphere.

Calculate the average loss per 100 square inches of leaf-surface for each plant throughout the whole course of the experiment. Divide the greater loss by the lesser to find their ratio. Find the ratio of each plant's greatest loss per day to its least loss per day, and by comparing these ratios decide which transpires more regularly.

Try the effect of supplying very little water to each, so that the hydrangea will begin to droop, and see whether this changes the relative amount of transpiration for the two plants. Vary the conditions of the experiment for a day or two as regards temperature, and again for a day or two as regards light, and note the effect upon the amount of transpiration.

The structure of the fig (India-rubber plant) leaf has already been studied. That of the hydrangea is looser in texture and more like the leaf of the lily or the beet (Fig. 116).

What light does the structure throw on the results of the preceding experiment?

[1] It will be much more convenient to tie the hydrangea if one has been chosen that has but a single main stem. Instead of the hydrangea, the common cineraria, *Senecio cruentus*, does very well.

[2] The addition of known amounts of water may be made most conveniently by measuring it in a cylindrical graduate.

EXPERIMENT XXXI

Through which Side of a Leaf of the India-Rubber Plant does Transpiration occur? — The student may already have found (Sect. 164) that there are no stomata on the upper surface of the fig leaf which he studied. That fact makes this leaf an excellent one by means of which to study the relation of stomata to transpiration.

Take two large, sound rubber-plant leaves, cut off pretty close to the stem of the plant. Slip over the cut end of the petiole of each leaf a piece of small rubber tubing, wire this on, leaving about half of it free, then double the free end over and wire tightly, so as to make the covering moisture-proof. Warm some vaseline or grafting wax until it is almost liquid, and spread a thin layer of it smoothly over the upper surface of one leaf and the lower surface of the other. Hang both up in a sunny place in the laboratory and watch them for a month or more.

What difference in the appearance of the two leaves becomes evident? What does the experiment prove?

172. Endurance of Drought by Plants. — Plants in a wild state have to live under extremely different conditions as regards water supply (see Chapter XXIV). Observation of growing plants during a long drought will quickly show how differently the various species of a region bear the hardships due to a scanty supply of moisture. It is still easier, however, to subject some plants to an artificial drought and watch their condition.

EXPERIMENT XXXII

Resistance to Drought. — Procure at least one plant from each of these groups:

Group I. Melon-cactus (*Echinocactus* or *Mamillaria*), prickly pear cactus.

Group II. Aloe, *Cotyledon* (often called *Echeveria*), houseleek.

Group III. Live-for-ever (*Sedum Telephium*), *Bryophyllum*, English ivy, "ivy-leafed geranium," (*Pelargonium peltatum*), or any of the fleshy-leafed begonias.

Group IV. Hydrangea (*H. Hortensia*), squash or cucumber, sunflower.

The plants should be growing in pots and well rooted. Water them well and then put them all in a warm, sunny place. Note the appearance of all the plants at the end of twenty-four hours. If any are wilting badly, water them. Keep on with the experiment, in no case watering any plant or set of plants until it has wilted a good deal. Record the observations in such a way as to show just how long a time it took each plant to begin to wilt from the time when the experiment began. If any hold out more than a month, they may afterwards be examined at intervals of a week, to save the time required for daily observations. If possible, account by the structure of the plants for some of the differences observed. Try to learn the native country of each plant used and the soil or exposure natural to it.

173. Course traversed by Water through the Leaf. — The same plan that was adopted to trace the course of water in the stem (Exp. XXI) may be followed to discover its path through the leaf.

EXPERIMENT XXXIII

Rise of Sap in Leaves. — Put the freshly cut ends of the petioles of several thin leaves of different kinds into small glasses, each containing eosin solution to the depth of one-quarter inch or more. Allow them to stand for half an hour, and examine them by holding up to the light and looking through them to see into what parts the eosin solution has risen. Allow some of the leaves to remain as much as twelve hours, and examine them again. The red-stained portions of the leaf mark the lines along which, under natural conditions, sap rises into it. Cut across (near the petiole or midrib ends) all the principal veins of some kind of large, thin leaf. Then cut off the petiole and at once stand the cut end, to which the blade

is attached, in eosin solution. Repeat with another leaf and stand in water. What do the results teach?

174. Total Amount of Transpiration. — In order to prevent wilting, the rise of sap during the life of the leaf must have kept pace with the evaporation from its surface. The total amount of water that travels through the roots, stems, and leaves of most seed-plants during their lifetime is large, relative to the weight of the plant itself. During 173 days of growth a corn-plant has been found to give off nearly 31 pounds of water. During 140 days of growth a sunflower-plant gave off about 145 pounds. A grass-plant has been found to give off its own weight of water every twenty-four hours in hot, dry summer weather. This would make about $6\frac{1}{2}$ tons per acre every twenty-four hours for an ordinary grass-field, or rather over 2200 pounds of water from a field 50×150 feet, that is, not larger than a good-sized city lot. Calculations based on observations made by the Austrian forest experiment stations showed that a birch tree with 200,000 leaves, standing in open ground, transpired on hot summer days from 700 to 900 pounds, while at other times the amount of transpiration was probably not more than 18 to 20 pounds.[1]

These large amounts of water are absorbed, carried through the tissues of the plant, and then given off by the leaves because the plant-food contained in the soil-water is in a condition so diluted that great quantities of water must be taken in order to secure enough of the mineral and other substances which the plant demands from the soil. Active transpiration may also have other causes.

[1] See B. E. Fernow's discussion in Report of Division of Forestry of U. S. Department of Agriculture, 1889.

Meadow hay contains about two per cent of potash, or 2000 parts in 100,000, while the soil-water of a good soil does not contain more than one-half part in 100,000 parts. It would therefore take 4000 tons of such water to furnish the potash for one ton of hay. The water which the root-hairs take up must, however, contain far more potash than is assumed in the calculation above given, so that the amount of water actually used in the growth of a ton of hay cannot be much more than 260 tons.[1]

175. Accumulation of Mineral Matter in the Leaf. — Just as a deposit of salt is found in the bottom of a seaside pool of salt water which has been dried up by the sun, so old leaves are found to be loaded with mineral matter, left behind as the sap drawn up from the roots is evaporated through the stomata. A bonfire of leaves makes a surprisingly large heap of ashes. An abundant constituent of the ashes of burnt leaves is silica, a substance chemically the same as sand. This the plant is forced to absorb along with the potash, compounds of phosphorus, and other useful substances contained in the soil-water; but since the silica is of hardly any value to most plants, it often accumulates in the leaf as so much refuse. Lime is much more useful to the plant than silica, but a far larger quantity of it is absorbed than is needed; hence it, too, accumulates in the leaf.

176. Nutrition, Metabolism.[2] — The manufacture of the more complex plant-foods, starch, sugar, and so on, from

[1] See the article, "Water as a Factor in the Growth of Plants," by B. T. Galloway and Albert F. Woods, *Year-Book of U. S. Department of Agriculture, 1894.*

[2] See Kerner and Oliver's *Natural History of Plants*, Vol. I, pp. 371–483. Also Pfeffer's *Physiology of Plants*, translated by Ewart, Chapter VIII.

the raw materials which are afforded by the earth and air and all the steps of the processes by which these foods are used in the life and growth of the plant are together known as its *nutrition.* When we think more of the chemical side of nutrition than of its relation to plant-life, we call any of the changes or all of them *metabolism*, which means simply chemical transformation in living tissues. There are two main classes of metabolism — the constructive kind, which embraces those changes which build up more complicated substances out of simpler ones (Sect. 179), and the destructive kind, the reverse of the former (Sect. 184). A good many references to cases of plant metabolism have been made in earlier chapters, but the subject comes up in more detail in connection with the study of the work of leaves than anywhere else, because the feeding which the ordinary seed-plant does is very largely done in and by its leaves.

177. Details of the Work of the Leaf. — A leaf has four functions to perform: (1) Starch-making; (2) assimilation;[1] (3) excretion of water; (4) respiration.

178. Absorption of Carbon Dioxide and Removal of its Carbon. — Carbon dioxide is a constant ingredient of the atmosphere, usually occurring in the proportion of about four parts in every 10,000 of air or one twenty-fifth of one per cent. It is a colorless gas, a compound of two simple substances or elements, carbon and oxygen, the former familiar to us in the forms of charcoal and graphite, the latter occurring as the active constituent of air.

[1] In many works on Botany (1) and (2) are both compounded under the term *assimilation.* Many botanists (most of the American ones) apply the name *photosynthesis* or *photosyntax* to the starch-making process, but these names are not wholly satisfactory, and perhaps it is as well (as suggested by Professor Atkinson) to name the process from its result.

Carbon dioxide is produced in immense quantities by the decay of vegetable and animal matter, by the respiration of animals, and by all fires in which wood, coal, gas, or petroleum is burned.

Green leaves and the green parts of plants, when they contain a suitable amount of potassium salts, have the power of removing carbon dioxide from the air (or in the case of some aquatic plants from water in which it is dissolved), retaining its carbon and setting free part or all of the oxygen. This process is an important part of the work done by the plant in making over raw materials into food from which it forms its own substance.

EXPERIMENT XXXIV

Oxygen-Making in Sunlight. — Place a green aquatic plant in a glass jar full of ice-cold fresh water, in front of a sunny window.[1] Place a thermometer in the jar, watch the rise of temperature, and note at what point you first observe the formation of oxygen bubbles. Remove to a dark closet for a few minutes and examine by lamplight, to see whether the rise of bubbles still continues.

This gas may be shown to be oxygen by collecting some of it in a small inverted test-tube filled with water and thrusting the glowing coal of a match just blown out into the gas. It is not, however, very easy to do this satisfactorily before the class.

Repeat the experiment, using water which has been well boiled and then quickly cooled. Boiling removes all the dissolved gases from water, and they are not re-dissolved in any considerable quantity for many hours.

[1] *Elodea*, *Myriophyllum*, *Chrysosplenium*, *Potamogeton*, *Fontinalis*, any of the green aquatic flowering plants, or even the common confervaceous plants, known as *pond-scum* or "frog-spit," will do for this experiment.

Ordinary air, containing a known per cent of carbon dioxide, if passed very slowly over the foliage of a plant covered with a bell-glass and placed in full sunlight, will, if tested chemically, on coming out of the bell-glass be found to have lost a little of its carbon dioxide. The pot in which the plant grows must be covered with a lid, closely sealed on, to prevent air charged with carbon dioxide (as the air of the soil is apt to be) from rising into the bell-glass.

179. Disposition made of the Absorbed Carbon Dioxide. — It would lead the student too far into the chemistry of botany to ask him to follow out in detail the changes by which carbon dioxide lets go part at least of its oxygen and gives its remaining portions, namely, the carbon, and perhaps part of its oxygen, to build up the substance of the plant. Starch is composed of three elements: hydrogen (a colorless, inflammable gas, the lightest of known substances), carbon, and oxygen. Water is composed largely of hydrogen, and, therefore, carbon dioxide and water contain all the elements necessary for making starch. The chemist cannot put these elements together to form starch, but the plant can do it, and at suitable temperatures starch-making goes on constantly in the green parts of plants when exposed to sunlight and supplied with water and carbon dioxide.[1] The seat of the manufacture is in the chlorophyll bodies, and protoplasm is without doubt the manufacturer, but the process is not understood by chemists or botanists. No carbon dioxide can be taken up and used by plants growing in the dark, nor in an atmosphere containing only carbon dioxide, even in the light.

[1] Very likely the plant makes sugar first of all and then rapidly changes this into starch. However that may be, the first kind of food made in the leaf and retained long enough to be found there by ordinary tests is starch. See Pfeffer's *Physiology of Plants*, translated by Ewart, Vol. I, pp. 317, 318.

PLATE V. — A Saprophyte, Indian Pipe

A very good comparison of the leaf to a mill has been made as follows[1]:

The mill:	Palisade-cells and underlying cells of the leaf.
Raw material used:	Carbon dioxide, water.
Milling apparatus:	Chlorophyll grains.
Energy by which the mill is run:	Sunlight.
Manufactured product:	Starch.
Waste product:	Oxygen.

180. Plants Destitute of Chlorophyll not Starch-Makers. — Aside from the fact that newly formed starch grains are first found in the chlorophyll bodies of the leaf and the green layer of the bark, one of the best evidences of the intimate relation of chlorophyll to starch-making is derived from the fact that plants which contain no chlorophyll cannot make starch from water and carbon dioxide. Parasites, like the dodder, which are nearly destitute of green coloring matter, cannot do this; neither can *saprophytes* or plants which live on decaying or fermenting organic matter, animal or vegetable. Most saprophytes, like the moulds, toadstools, and yeast, are flowerless plants of low organization, but there are a few (such as the Indian pipe (Plate V), which flourishes on rotten wood or among decaying leaves) that bear flowers and seeds.

181. Detection of Starch in Leaves. — Starch may be found in abundance by microscopical examination of the green parts of growing leaves, or its presence may be shown by testing the whole leaf with iodine solution.

[1] By Professor George L. Goodale.

EXPERIMENT XXXV

Occurrence of Starch in Nasturtium Leaves. — Toward the close of a very sunny day collect some bean leaves or leaves of nasturtium (*Tropæolum*). Boil these in water for a few minutes, to kill the protoplasmic contents of the cells and to soften and swell the starch grains.[1]

Soak the leaves, after boiling, in strong alcohol for a day or two, to dissolve out the chlorophyll, which would otherwise make it difficult to see the blue color of the starch test, if any were obtained. Rinse out the alcohol with plenty of water and then place the leaves for ten or fifteen minutes in a solution of iodine, rinse off with water and note what portions of the leaf, if any, show the presence of starch.

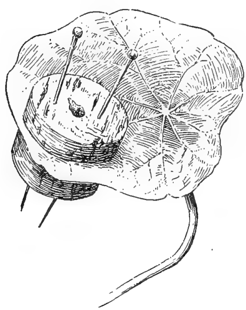


FIG. 123. — Leaf of Tropæolum partly covered with Disks of Cork and exposed to Sunlight.

EXPERIMENT XXXVI

Consumption of Starch in Nasturtium (*Tropæolum*) Leaves. — Select some healthy leaves of Tropæolum on a plant growing vigorously indoors or, still better, in the open air. Shut off the sunlight from parts of the selected leaves (which are to be left on the plant and as little injured as may be) by pinning circular disks of cork on opposite sides of the leaf, as shown in Fig. 123. On the afternoon of the next day remove these leaves from the plant and treat as described in the preceding experiment, taking especial pains to get rid of all the chlorophyll by changing the alcohol as many times as may be necessary. What does this experiment show in regard to the consumption of starch in the leaf? What has caused its disappearance?

182. Rate at which Starch is manufactured. — The amount of starch made in a day by any given area of

[1] The leaves, collected as above described, may, after boiling, be kept in alcohol for winter use. They also make excellent material for the microscopical study of starch in the leaf.

foliage must depend on the kind of leaves, the temperature of the air, the intensity of the sunlight, and some other circumstances. Sunflower leaves and pumpkin or squash leaves have been found to manufacture starch at about the same rate. In a summer day fifteen hours long they can make nearly three-quarters of an ounce of starch for each square yard of leaf-surface. A full-grown squash leaf has an area of about one and one-eighth square feet, and a plant may bear as many as 100 leaves. What would be the daily starch-making capacity of such a plant?[1]

183. Assimilation. — From the starch in the leaf, grape-sugar or malt-sugar is readily formed, and some of this in turn is apparently combined on the spot with nitrogen, sulphur, and phosphorus. These elements are derived from nitrates, sulphates, and phosphates, taken up in a dissolved condition by the roots of the plant and transported to the leaves. The details of the process are not understood, but the result of the combination of the sugars or similar substances with suitable (very minute) proportions of nitrogen, sulphur, and phosphorus is to form complex nitrogen compounds. These are not precisely of the same composition as the living protoplasm of plant-cells or as the reserve proteids stored in seeds (Sects. 14, 17), stems (Sect. 127), and other parts of plants, but are readily changed into protoplasm or proteid foods as necessity may demand.

Assimilation is by no means confined to leaves; indeed, most of it, as above suggested, must take place in other parts of the plant. For instance, the manufacture of the immense amounts of cellulose, of cork, and of the com-

[1] See Pfeffer's *Physiology of Plants*, translated by Ewart, Vol. I, p. 324.

pound (*lignin*) characteristic of wood-fiber, that go to make up the main bulk of a large tree must be carried on in the roots, trunk, and branches of the tree.

184. Digestive Metabolism. — Plant-food in order to be carried to the parts where it is needed must be dissolved, and this dissolving often involves a chemical change and is somewhat similar to digestion as it occurs in animals. The newly made starch in the leaf must be changed to a sugar or other substance soluble in water before it can be carried to the parts of the plant where it is to be stored or to rapidly growing parts where it is to be used for building material. On the other hand, starch, oil, and such insoluble proteids as are deposited in the outer portion of the kernel of wheat and other grains are extremely well adapted to serve as stored food, but on account of their insoluble nature are quite unfit to circulate through the tissues of the plant. The various kinds of sugar are not well adapted for storage, since they ferment easily in the presence of warmth and moisture if yeast-cells or suitable kinds of bacteria are present.

Two important differences between starch-making in the green parts of plants and the non-constructive or the destructive type of metabolism should be carefully noticed. These latter kinds of metabolism go on in the dark as well as in the light and do not add to the total weight of the plant.

185. Excretion of Water and Respiration. — Enough has been said in Sect. 174 concerning the former of these processes. *Respiration*, or breathing in oxygen and giving off carbonic acid gas, is an operation which goes on constantly in plants, as it does in animals, and is necessary to

their life. For, like animals, plants get the energy with which they do the work of assimilation, growth, reproduction, and performing their movements from the oxidation of such combustible substances as oil, starch, and sugar.[1]

The amount of oxygen absorbed and of carbonic acid given off is, however, so trifling compared with the amount of each gas passing in the opposite direction, while starch-making is going on in sunlight, that under such circumstances it is difficult to observe the occurrence of respiration. In ordinary leafy plants the leaves (through their stomata) are the principal organs for absorption of air, but much air passes into the plant through the lenticels of the bark.

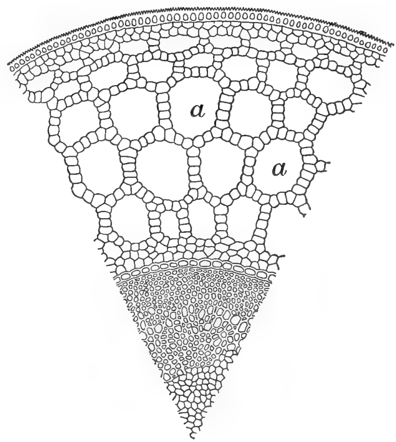


FIG. 124.—Cross-Section of Stem of Marestail (*Hippuris*) with Air-Passages, *a*.

In partly submerged aquatics especial provisions are found for carrying the air absorbed by the leaves down to the submerged parts. This is accomplished in pond lilies by ventilating tubes which traverse the leaf-stalks lengthwise. In many cases such channels run up and down the stem (Fig. 124).

[1] The necessity of an air supply about the roots of the plant may be shown by filling the pot or jar in which the hydrangea was grown for the transpiration experiment perfectly full of water and noting the subsequent appearance of the plant at periods twelve to twenty-four hours apart.

186. Tabular Summary of Metabolic and Other Processes.[1]

Name of Process	By what Apparatus or Agency carried on	By what Kind of Energy carried on	Substances acted on	Useful Products	Waste Products
Starch-making	Chlorophyll bodies of leaves and green stems	Sunlight and heat, energy of protoplasm	Carbon dioxide and water	Sugar and starch	Oxygen, passed out of stomata
Assimilation (Tissue Building)	Living protoplasm in leaves and elsewhere		Sugar and compounds containing nitrogen, sulphur, and phosphorus	Proteids for storage. Protoplasm for live, active cells	
Digestion	Various ferments or enzymes		Starch, cellulose, stored proteids	Sugars, proteids in soluble forms	
Excretion of water (Transpiration)	Cells of pulpy interior of leaf around air spaces	Heat, vaporizing water	Soil-water brought up from roots	Potassium salts and other useful inorganic compounds stored	Water vapor, passed out of stomata. Lime salts, silica, etc., deposited in the leaf
Respiration (Breathing)	All live cells of interior of root, stem or leaf when supplied with air	Chemical attraction between oxygen and combustible substances	Sugars and oils	Energy (*i.e.*, power to do work)	Carbonic acid gas, water

[1] It is to be understood that this table only includes a small portion of the whole series of metabolic processes which go on in green plants, but it embraces some of the most important ones. Excretion of water is not a metabolic process, but is inserted here for the purpose of making the showing of the work of the leaf as complete as possible.

187. The Fall of the Leaf. — In the tropics trees retain most of their leaves the year round; a leaf occasionally falls, but no considerable portion of them drops at any one season.[1] The same statement holds true in regard to our cone-bearing evergreen trees, such as pines, spruces, and the like. But the impossibility of absorbing soil-water when the ground is at or near the freezing temperature (Exp. XVII) would cause the death, by drying up, of trees with broad leaf-surfaces in a northern winter. And in countries where there is much snowfall, most broad-leafed trees could not escape injury to their branches from overloading with snow, except by encountering winter storms in as close-reefed a condition as possible. For such reasons our common shrubs and forest trees (except the cone-bearing, narrow-leafed ones already mentioned) are mostly *deciduous*, that is they shed their leaves at the approach of winter.

The fall of the leaf is preceded by important changes in the contents of its cells.

EXPERIMENT XXXVII

Does the Leaf vary in its Starch Contents at Different Seasons?

Collect in early summer some leaves of several kinds of trees and shrubs and preserve them in alcohol. Collect others as they are beginning to drop from the trees in autumn and preserve them in the same way. Test some of each lot for starch as described in Sect. 181.

What does the result indicate?

Much of the sugary and protoplasmic contents of the leaf disappears before it falls. These valuable materials

[1] Except where there is a severe dry season.

have been absorbed by the branches and roots, to be used again the following spring.

The separation of the leaf from the twig is accomplished by the formation of a layer of cork cells across the base of the petiole in such a way that the latter finally breaks off across the surface of the layer. A waterproof scar is thus already formed before the removal of the leaf, and there is no waste of sap dripping from the wound where the leaf-stalk has been removed, and no chance for moulds to attack the bark or wood and cause it to decay. In compound leaves each leaflet may become separated from the petiole, as is notably the case with the horse-chestnut leaf (Fig. 102). In woody monocotyledons, such as palms, the leaf-stalks do not commonly break squarely off at the base, but wither and leave projecting stumps on the stem (Plate VI).

The brilliant coloration, yellow, scarlet, deep red, and purple, of autumn leaves is popularly but wrongly supposed to be due to the action of frost. It depends merely on the changes in the chlorophyll grains and the liquid cell-contents that accompany the withdrawal of the proteid material from the tissues of the leaf. The chlorophyll turns into a yellow insoluble substance after the valuable materials which accompany it have been taken away, and the cell sap at the same time may turn red. Frost perhaps hastens the break-up of the chlorophyll, but individual trees often show bright colors long before the first frost, and in very warm autumns most of the changes in the foliage may come about before there has been any frost.

188. Tabular Review of Experiments.

[Continue the table from Sect. 128.]

PLATE VI. — Fan Palms

189. Review Summary of Minute Structure of Leaves.[1]

General structure, distribution of parenchyma, and prosenchyma
Layers of tissue seen on a cross-section . . . .
Structure of epidermis . . .
Structure of stomata . . . .
Distribution of stomata . . .
Structure and distribution of chlorophyll bodies . . . .

190. Review Summary of Functions of Leaves.

Principal uses of . . . .
- fibro-vascular bundles
- epidermis . . . .
- stomata . . . .
- air spaces . . . .
- palisade-cells . . .
- spongy parenchyma
- waxy coating . . .
- hairs . . . . .

Substances received by the leaf . . . .
- from the air . . .
- from the soil . . .

Substances manufactured by the leaf . .

Substances given off by the leaf . . .
- into the air . . .
- into the stem . .

Mineral substances accumulated in the leaf
Statistics in regard to transpiration . .
Statistics in regard to starch-making . .

[1] Illustrate with sketches and diagrams.

CHAPTER XII

PROTOPLASM AND ITS PROPERTIES

191. The Cell in its Simplest Form. — Sufficient has been said in the preceding chapters, and enough tissues have been microscopically studied, to make it pretty clear what vegetable cells, as they occur in flowering plants, are like. In Chapter XI, leaf-cells have been taken for granted and their work described in some detail. Before going further, it is worth while to consider the structure of an individual cell, and to see of what kinds of activity it is capable.

In studying the minute anatomy of bark, wood, pith, and other tissues the attention is often directed to the *cell-wall* without much regard to the nature of the *cell-contents.* Yet the cell-wall is not the cell, any more than the lobster shell or the crayfish shell is the lobster or the crayfish. *The contained protoplasm with its nucleus is the cell.*[1] The cell reduced to its lowest terms need not have a cell-wall, but may consist simply of a mass of protoplasm, usually containing a portion of denser consistency than the main bulk, known as the *nucleus.*

Such cells, without a cell-wall, are not common in the vegetable world, but are frequently encountered among animals.

192. The Slime Moulds.[2] — One of the best examples of masses of naked protoplasm leading an individual existence

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. I, pp. 21–51.

[2] Strasburger, Noll, Schenk, and Schimper's *Text-Book of Botany*, pp. 50–52 and 302–305.

is found in the slime moulds, which live upon rotten tan bark, decaying wood, and so on. These curious organisms have so many of the characteristics both of animals and of plants that they have been described in zoölogies under the former title and in botanies under the latter one. Perhaps it would not really be so absurd a statement as it might seem, to say that every slime mould leads the life of an animal during one period of its existence and of a plant at another period. At any rate, whatever their true nature, these little masses of unenclosed protoplasm illustrate admirably some of the most important properties of protoplasm. Slime moulds spring from minute bodies called *spores* (Fig. 125, *a*) which differ from the seeds of seed-plants not only in their microscopic size but still more in their lack of an embryo. The spores of slime moulds are capable, when kept dry, of preserving for many years their power of germination, but in the presence of moisture and warmth they will germinate as soon as they are scattered. During the process of germination the spore swells, as shown at *b*, and then bursts, discharging its protoplasmic contents, as seen at *c* and *d*. This in a few minutes lengthens out and produces at one end a hair-like *cilium*, as shown at *e*, *f*, *g*. These ciliated bodies are called *swarmspores*, from their power of swimming freely about by the vibrating motion of the cilia. Every swarmspore has at its ciliated end a *nucleus*, and at the other end a bubble-like object which gradually expands, quickly disappears, and then again expands. This *contractile vacuole* is commonly met with in animalcules, and increases the likeness between the slime moulds and many microscopic animals. The next change of the swarmspores is into an

Amœba form (so called from one of the most interesting and simplest of animals, the *Amœba*, found on the surface of

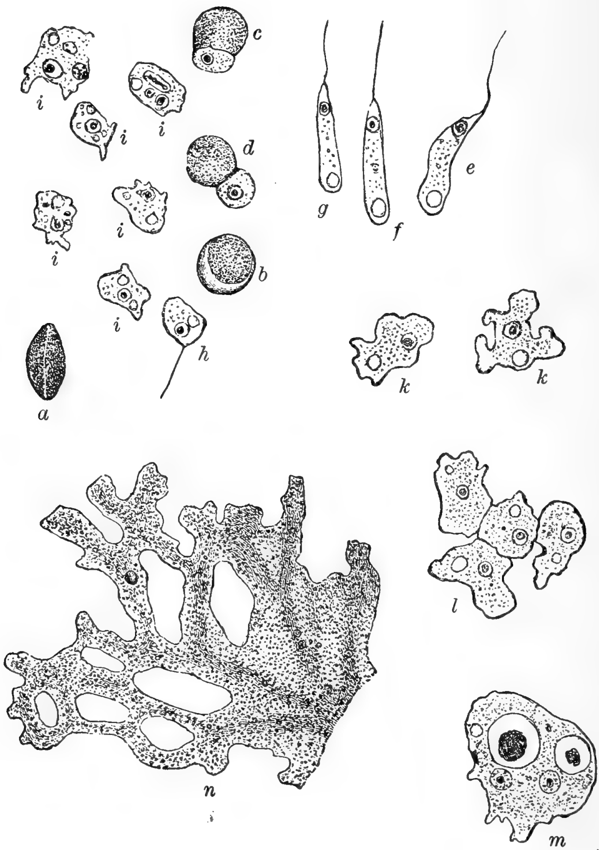


FIG. 125. — A Slime Mould. (*a–m*, inclusive, × 540 times, *n* × 90 times.)

mud and the leaves of water plants). In this condition, as shown at *h*, *i*, *k*, the spores creep about over the surface of the decaying vegetable material on which the

slime moulds live. Their movement is caused by a thrusting out of the semi-liquid protoplasm on one side of the mass, and a withdrawal of its substance from the other side. At length many amœba-shaped bodies unite, as at *l*, to form a larger mass, *m*, which finally increases to the protoplasmic network shown at *n*. This eventually collects into a roundish or egg-shaped firm body, inside of which a new crop of spores is produced. It is not easy to trace the manner in which the nourishment of these simple plants is taken. Probably they absorb it from the decaying matter upon which they live during their amœba-like period, and after they have formed the larger masses, *n*.

193. Characteristics of Living Protoplasm.[1] — The behavior of the slime moulds during their growth and transformations, as just outlined, affords a fair idea of several of the remarkable powers which belong to living protoplasm, which have been summed up as follows:

(1) The power to take up new material into its own substance (*selective absorption*). This is not merely a process of soaking up liquids, such as occurs when dry earth or a sponge is moistened. The protoplasmic lining of a root-hair, for example, selects from the soil-water some substances and rejects others (Sect. 65).

(2) The ability to change certain substances into others of different chemical composition (*metabolism*, Sect. 176). Carbon dioxide and water, losing some oxygen in the process, are combined into starch; starch is changed into various kinds of sugar and these back into starch again; starch becomes converted into vegetable acids, into cellulose, or into oil; or the elements of starch are combined

[1] See Huxley's *Essays*, Vol. I, essay on "The Physical Basis of Life."

with nitrogen to make various proteid compounds, either for immediate use or for reserve food. Many other complicated transformations occur.

(3) The power to cast off waste or used-up material (*excretion*). Getting rid of surplus water (Sect. 174) and of oxygen (Sect. 178) constitutes a very large part of the excretory work of plants.

(4) The capacity for growth and the production of offspring (*reproduction*). These are especially characteristic of living protoplasm. It is true that non-living objects may grow in a certain sense, as an icicle or a crystal of salt or of alum in a solution of its own material does. But growth by the process of taking suitable particles into the interior of the growing substance and arranging them into an orderly structure (Fig. 126) is possible only in the case of live protoplasm.

(5) The possession of the power of originating movements not wholly and directly caused by any external impulse (*automatic movements*). Such, for instance, are the lashing movements of the cilia of the swarmspores of slime moulds, or the slow pendulum movements of *Oscillatoria* (Sect. 269), or the slow vibrating movements of the stipules of the "telegraph plant" (*Desmodium*), not uncommon in greenhouses.

(6) The power of shrinking or closing up (*contractility*). This is illustrated by the action of the contractile vacuole of the slime moulds and of many animalcules and by all the muscular movements of animals.

(7) Sensitiveness when touched or otherwise disturbed, for instance, by a change of light or of temperature (*irritability*).

194. Nature and Occurrence of Irritability in Plants.[1] — Mention has already been made of the fact that certain parts of plants respond to suitable *stimuli* that is exciting

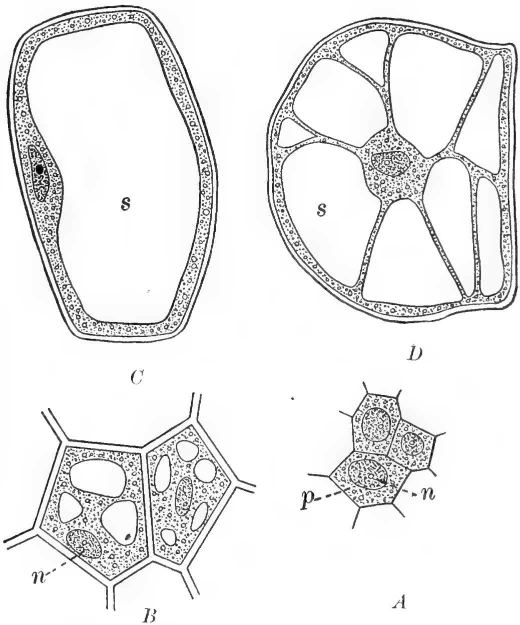


FIG. 126. — Protoplasm in Ovule and Fruit of Snowberry (*Symphoricarpus racemosus*).

A, cells from ovule, × 340; *B*, cells from an ovule further developed, × 340; *C*, *D*, cells from pulp of fruit, × 110; *n*, nucleus; *p*, protoplasm; *s*, cell-sap.

In the young and rapidly growing cells, *A* and *B*, the cell-sap is not present, or present only in small quantities, while in the older cells, *C* and *D*, it occupies a large portion of the interior of the cell.

causes. Geotropic movements (Sect. 70) are due to the response of roots or shoots to gravitation. These

[1] See Strasburger, Noll, Schenk, and Schimper's *Text-Book of Botany*, pp. 160–162 and 269–274.

movements are due to unequal growth induced in the younger portions of the plant by the action of gravitation upon it. Other movements (of ordinary foliage leaves, of the floral leaves of many flowers, and of other parts of a few flowers) are produced by changes in the distention or *turgescence* of some of the cells in the organs which move and have nothing to do with growth. The closing of the leaves of insect-catching plants is briefly described in Sect. 410, and the "sleep" of leaves, due to movements of the pulvini, was described in Sect. 152. A few facts in regard to the opening and closing of flowers will be found in Sect. 440.

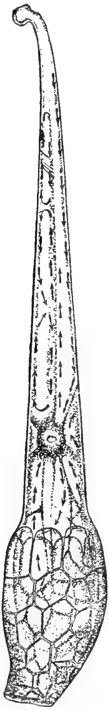


FIG. 127. — Stinging Hair of Nettle, with Nucleus. (Much magnified.) The arrows show the direction of the currents in the protoplasm.

The stimuli which cause movements of leaves or of the irritable parts of flowers are of several kinds. Light is the main cause which induces leaves to open from their night position to that usual in the daytime. In the case of flowers, it is sometimes light and sometimes warmth which causes them to open. Leaves which catch insects may be made to close by touching them, but the sensitive-plants, of which there are several kinds found in the United States, and a much more sensitive one in tropical America, all fold their leaflets, on being touched, into the same position which they assume at night.

195. Circulation of Protoplasm. — When confined by a cell-wall, protoplasm often manifests a beautiful and constant rotating movement, traveling incessantly up one side of the cell and down the other.[1] A more complicated motion is the *circulation of protoplasm*, shown in cells of the jointed blue hairs in the flower of the common spiderwort and in the stinging hairs of the nettle (Fig. 127). The thin cell-wall of each hair is lined with a protoplasmic layer in which are seen many irregular, thread-like currents, marked by the movements of the granules, of which the protoplasmic layer is full.

[1] See Huxley and Martin's *Elementary Biology*, under *Chara*.

CHAPTER XIII

INFLORESCENCE, OR ARRANGEMENT OF FLOWERS ON THE STEM

196. Regular Positions for Flower-Buds. — Flower-buds, like leaf-buds, occur regularly either in the axils of leaves or at the end of the stem or branch and are therefore either axillary or terminal.

197. Axillary and Solitary Flowers; Indeterminate Inflorescence. — The simplest possible arrangement for flowers which arise from the axils of leaves is to have a single flower spring from each leaf-axil. Fig. 128 shows how this plan appears in a plant with opposite leaves. As long as the stem continues to grow, the production of new leaves may be followed by that of new flowers. Since there is no definite limit to the number of flowers which may appear in this way, the mode of flowering just described (with many others of the same general character) is known as *indeterminate inflorescence.*

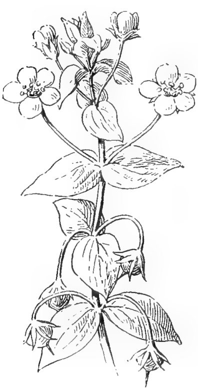


FIG. 128. — Axillary and Solitary Flowers of Pimpernel.

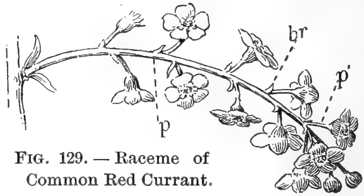


FIG. 129. — Raceme of Common Red Currant.
p, peduncle; *p'*, pedicel; *br*, bract.

198. The Racemes and Related Forms. — If the leaves along the stem were to become very much dwarfed and the flowers brought closer together, as they frequently are, a kind of flower-cluster like that of the currant (Fig. 129) or the lily-of-the-valley would result. Such an inflorescence is called a *raceme;* the main flower-stalk is known as the *peduncle;* the little individual flower-stalks are *pedicels,* and the small, more or less scale-like leaves of the peduncle are *bracts.*[1]

FIG. 130. — Simple Umbel of Cherry.

Frequently the lower pedicels of a cluster on the general plan of the raceme are longer than the upper ones and make a somewhat flat-topped cluster, like that of the hawthorn, the sheep laurel, or the trumpet creeper. This is called a *corymb.*

In many cases, for example the parsnip, the Sweet Cicely, the ginseng, and the cherry, a group of pedicels of nearly equal length

FIG. 131. — Catkins of Willow.

A, staminate flowers; *B*, pistillate flowers

[1] It is hardly necessary to say that the teacher will find it better in every way, if material is abundant, to begin the study of flower-clusters with the examination of typical specimens by the class.

spring from about the same point. This produces a flower-cluster called the *umbel* (Fig. 130).

199. Sessile Flowers and Flower-Clusters. — Often the pedicels are wanting, or the flowers are sessile, and then a modification of the raceme is produced which is called a *spike*, like that of the plantain (Fig. 132). The willow, alder, birch, poplar, and many other common trees bear a short, flexible, rather scaly spike (Fig. 131), which is called a *catkin*.

The peduncle of a spike is often so much shortened as to bring the flowers into a somewhat globular mass. This is called a *head* (Fig. 132). Around the base of the head usually occurs a circle of bracts known as the *involucre*. The same name is given to a set of bracts which often surround the bases of the pedicels in an umbel.

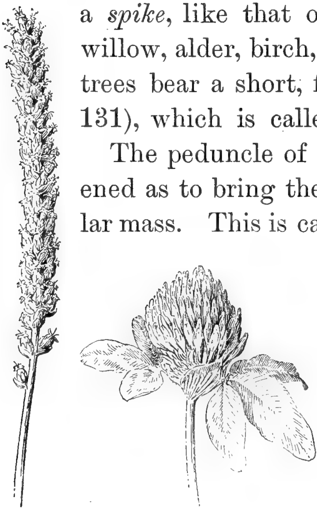


FIG. 132. — Spike of Plantain and Head of Red Clover.

200. The Composite Head. — The plants of one large group, of which the dandelion, the daisy, the thistle, and the sunflower are well-known members, bear their flowers in close involucrate heads on a common receptacle. The whole cluster looks so much like a single flower that it is usually taken for one by non-botanical people. In many of the largest and most showy heads, like that of the sunflower and the daisy, there are two kinds of flowers, the *ray-flowers*, around the margin, and the tubular *disk-flowers* of the interior of the head (Fig. 133). The early botanists supposed the whole flower-cluster to be a single

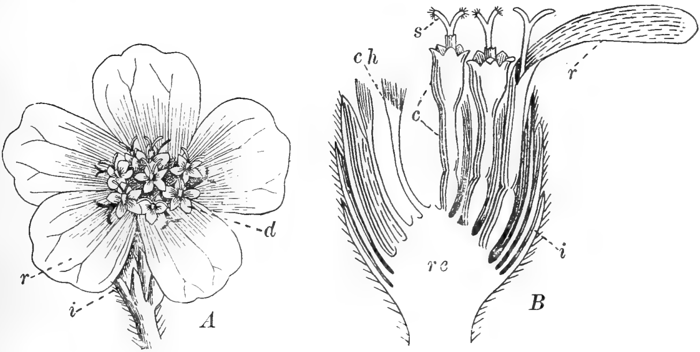


FIG. 133. — Head of Yarrow.

A, top view. (Magnified.) *B*, lengthwise section. (Magnified.) *re*, receptacle; *i*, involucre; *r*, ray-flowers; *d*, disk-flowers; *c*, corolla; *s*, stigma; *ch*, chaff, or bracts of receptacle.

FIG. 134.
Panicle of Oat.

FIG. 135. — Compound Umbel
of Carrot.

compound flower. This belief gave rise to the name of one family of plants, *Compositæ*, that is, plants with compound flowers. In such heads as those of the thistle, the cud weed, and the everlasting there are no ray-flowers, and in others, like those of the dandelion and the chicory, all the flowers are ray-flowers.

201. Compound Flower-Clusters. — If the pedicels of a raceme branch, they may produce a compound raceme, or

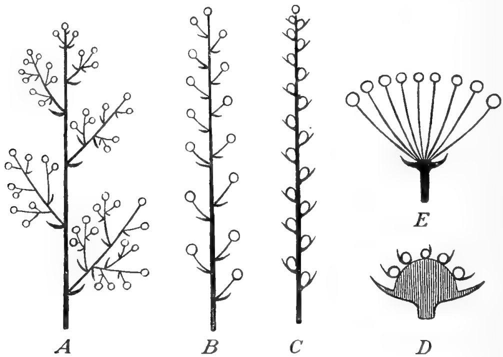


FIG. 136. — Diagrams of Inflorescence.
A, panicle; *B*, raceme; *C*, spike; *E*, umbel; *D*, head.

panicle, like that of the oat (Fig. 134).[1] Other forms of compound racemes have received other names.

An umbel may become compound by the branching of its flower-stalks (Fig. 135), each of which then bears a little umbel, an *umbellet*.

202. Inflorescence Diagrams. — The plan of inflorescence may readily be indicated by diagrams like those of Fig. 136.

The student should construct such diagrams for some rather complicated flower-clusters, like those of the grape, horse-chestnut or buckeye, hardhack, vervain, or many grasses.

[1] Panicles may also be formed by compound cymes (see Sect. 204).

203. Terminal Flowers; Determinate Inflorescence. — The terminal bud of a stem may be a flower-bud. In this case the direct growth of the stem is stopped or determined by the appearance of the flower; hence such plants are said to have a *determinate inflorescence.* The simplest possible case of this kind is that in which the stem bears but one flower at its summit.

204. The Cyme. — Very often flowers appear from lateral (axillary) buds, below the terminal flower, and thus give rise to a flower-cluster called a *cyme.* This may have only three flowers, and in that case would look very much like a three-flowered umbel. But in the raceme, corymb, and umbel the order of flowering is from below upward, or from the outside of the cluster inward, because the lowest or the outermost flowers are the oldest, while in determinate forms of inflorescence the central flower is the oldest, and therefore the order of blossoming is from the center outwards. Cymes are very commonly compound, like those of the elder and of many plants of the pink family, such as the Sweet William and the mouse-ear chickweed (Fig. 137). They may also, as already mentioned, be panicled, thus making a cluster much like Fig. 136, *A*.

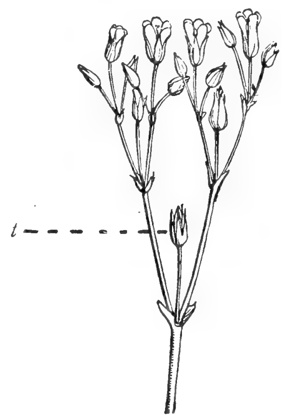


FIG. 137. — Compound Cyme of Mouse-Ear Chickweed. *t*, the terminal (oldest) flower.

CHAPTER XIV

THE STUDY OF TYPICAL FLOWERS

(Only one of the three flowers described to be studied by aid of these directions.)

205. The Flower of the Trillium. — Cut off the flower-stalk rather close to the flower; stand the latter, face down, on the table, and draw the parts then shown. Label the green leaf-like parts *sepals*, and the white parts, which alternate with these, *petals*. Turn the flower face up, and make another sketch, labeling the parts as before, together with the yellow enlarged extremities or *anthers* of the stalked organs called *stamens*.

Note and describe the way in which the petals alternate with the sepals. Observe the arrangement of the edges of the petals toward the base, — how many with both edges outside the others, how many with both edges inside, how many with one edge in and one out.

Note the veining of both sepals and petals, more distinct in which set?[1]

Pull off a sepal and make a sketch of it, natural size; then remove a petal, flatten it out, and sketch it, natural size.

Observe that the flower-stalk is enlarged slightly at the upper end into a rounded portion, the *receptacle*, on which all the parts of the flower rest.

Note how the six stamens arise from the receptacle and their relations to the origins of the petals. Remove the remaining petals

[1] In flowers with delicate white petals the distribution of the fibro-vascular bundles in these can usually be readily shown by standing the freshly cut end of the peduncle in red ink for a short time, until colored veins begin to appear in the petals. The experiment succeeds readily with apple, cherry, or plum blossoms; with white gilliflower the coloration is very prompt. Lily-of-the-valley is perhaps as interesting a flower as any on which to try the experiment, since the well-defined stained stripes are separated by portions quite free from stain, and the pistils are also colored.

(cutting them off near the bottom with a knife), and sketch the stamens, together with the other object, the *pistil*, which stands in the center.

Cut off one stamen, and sketch it as seen through the magnifying glass. Notice that it consists of a greenish stalk, the *filament*, and a broader portion, the *anther* (Fig. 149). The latter is easily seen to contain a prolongation of the green filament, nearly surrounded by a yellow substance. In the bud it will be found that the anther consists of two long pouches or *anther-cells*, which are attached by their whole length to the filament, and face inward (towards the center of the flower). When the flower is fairly open, the anther-cells have already split down their margins, and are discharging a yellow, somewhat sticky powder, the *pollen*.

Examine one of the anthers with the microscope, using the two-inch objective, and sketch it.

Cut away all the stamens, and sketch the *pistil*. It consists of a stout lower portion, the *ovary*, which is six-ridged or angled, and which bears at its summit three slender *stigmas*.

In another flower, which has begun to wither (and in which the ovary is larger than in a newly opened flower), cut the ovary across about the middle, and try to make out with the magnifying glass the number of chambers or *cells* which it contains. Examine the cross-section with the two-inch objective; sketch it, and note particularly the appearance and mode of attachment of the undeveloped seeds or *ovules* with which it is filled. Make a vertical section of another rather mature ovary, and examine this in the same way.

Using a fresh flower, construct a diagram to show the relation of the parts on an imaginary cross-section, as illustrated in Fig. 157.[1] Construct a diagram of a longitudinal section of the flower, on the general plan of those in Fig. 155, but showing the contents of the ovary.

Make a tabular list of the parts of the flower, beginning with the sepals, giving the order of parts and number in each set.

[1] It is important to notice that such a diagram is not a picture of the section actually produced by cutting through the flower crosswise at any one level, but that it is rather a *projection* of the sections through the most typical part of each of the floral organs.

206. The Flower of the Tulip.[1] — Make a diagram of a side view of the well-opened flower, as it appears when standing in sunlight. Observe that there is a set of outer flower-leaves and a set of inner ones.[2] Label the outer set *sepals* and the inner set *petals*. In most flowers the parts of the outer set are greenish, and those of the inner set of some other color. It is often convenient to use the name *perianth*, meaning around the flower, for the two sets taken together. Note the white waxy bloom on the outer surface of the outer segments of the perianth. What is the use of this? Note the manner in which the inner segments of the perianth arise from the top of the peduncle and their relation to the points of attachment of the outer segments. In a flower not too widely opened, note the relative position of the inner segments of the perianth, how many wholly outside the other two, how many wholly inside, how many with one edge in and one edge out.

Remove one of the sepals by cutting it off close to its attachment to the peduncle, and examine the veining by holding it up in a strong light and looking through it. Make a sketch to show the general outline and the shape of the tip.

Examine a petal in the same way, and sketch it.

Cut off the remaining portions of the perianth, leaving about a quarter of an inch at the base of each segment. Sketch the upright, triangular, pillar-like object in the center, label it *pistil*, sketch the organs which spring from around its base, and label these *stamens*.

Note the fact that each stamen arises from a point just above and within the base of a segment of the perianth. Each stamen consists of a somewhat conical or awl-shaped portion below, the *filament*, surmounted by an ovate linear portion, the *anther*. Sketch one of the stamens about twice natural size and label it × 2. Is the attachment of the anther to the filament such as to admit of any nodding or twisting movement of the former? In a young flower, note the two tubular pouches or anther-cells of which the anther is composed, and the slits by which these open. Observe the dark-colored *pollen*

[1] *Tulipa Gesneriana*. As the flowers are rather expensive, and their parts are large and firm, it is not absolutely necessary to give a flower to each pupil, but some may be kept entire for sketching and others dissected by the class. All the flowers must be single.

[2] Best seen in a flower which is just opening.

which escapes from the anther-cells and adheres to paper or to the fingers. Examine a newly opened anther with the microscope, using the two-inch objective, and sketch it.

Cut away all the stamens and note the two portions of the pistil, a triangular prism, the *ovary*, and three roughened scroll-like objects at the top, the three lobes of the *stigma*. Make a sketch of these parts about twice natural size, and label them × 2. Touch a small camel's-hair pencil to one of the anthers, and then transfer the pollen thus removed to the stigma. This operation is merely an imitation of the work done by insects which visit the flowers out of doors. Does the pollen cling readily to the rough stigmatic surface? Examine this adhering pollen with the two-inch objective, and sketch a few grains of it, together with the bit of the stigma to which it clings. Compare this drawing with Fig. 162. Make a cross-section of the ovary about midway of its length, and sketch the section as seen through the magnifying glass. Label the three chambers shown *cells of the ovary* [1] or *locules*, and the white egg-shaped objects within *ovules*.[2]

Make a longitudinal section of another ovary, taking pains to secure a good view of the ovules, and sketch as seen through the magnifying glass.

Making use of the information already gained and the cross-section of the ovary as sketched, construct a diagram of a cross-section of the entire flower on the same general plan as those shown in Fig. 157.[3]

Split a flower lengthwise,[4] and construct a longitudinal section of the entire flower on the plan of those shown in Fig. 155, but showing the contents of the ovary.

207. The Flower of the Buttercup. — Make a diagram of the mature flower as seen in a side view, looking a little down into it. Label the pale greenish-yellow, hairy, outermost parts *sepals*, and

[1] Notice that the word *cell* here means a comparatively large cavity, and is not used in the same sense in which we speak of a wood-cell or a pith-cell.

[2] The section will be more satisfactory if made from an older flower, grown out of doors, from which the perianth has fallen. In this case label the contained objects *seeds*.

[3] Consult also the footnote on p. 193.

[4] One will do for an entire division of the class.

the larger bright yellow parts above and within these *petals*, and the yellow-knobbed parts which occupy a good deal of the interior of the flower *stamens.*

Note the difference in the position of the sepals of a newly opened flower and that of the sepals of a flower which has opened as widely as possible. Note the way in which the petals are arranged in relation to the sepals. In an opening flower observe the arrangement of the edges of the petals, how many entirely outside the others, how many entirely inside, how many with one edge in and the other out.

Cut off a sepal and a petal, each close to its attachment to the flower; place both, face down, on a sheet of paper, and sketch about twice the natural size and label it × 2. Describe the difference in appearance between the outer and the inner surface of the sepal and of the petal. Note the little scale at the base of the petal, inside.

Strip off all the parts from a flower which has lost its petals, until nothing is left but a slender conical object a little more than an eighth of an inch in length. This is the *receptacle* or summit of the peduncle.

In a fully opened flower, note the numerous yellow-tipped *stamens*, each consisting of a short stalk, the *filament*, and an enlarged yellow knob at the end, the *anther.* Note the division of the anther into two portions, which appear from the outside as parallel ridges, but which are really closed tubes, the *anther-cells.*

Observe in the interior of the flower the somewhat globular mass (in a young flower almost covered by the stamens). This is a group of *pistils.* Study one of these groups in a flower from which the stamens have mostly fallen off, and make an enlarged sketch of the head of pistils. Remove some of the pistils from a mature head, and sketch a single one as seen with the magnifying glass. Label the little knob or beak at the upper end of the pistil *stigma*, and the main body of the pistil the *ovary.* Make a section of one of the pistils, parallel to the flattened surfaces, like that shown in Fig. 150, and note the partially matured seed within.

CHAPTER XV

PLAN AND STRUCTURE OF THE FLOWER AND ITS ORGANS

208. Parts or Organs of the Flower. — Most showy flowers consist, like those studied in the preceding chapter, of four circles or sets of organs, the sepals, petals, stamens, and pistils. The sepals, taken together, constitute the *calyx;* the petals, taken together, constitute the *corolla* (Fig. 138).[1] Sometimes it is convenient to have a word to comprise both calyx and corolla; for this the term *perianth* is used. A flower which contains all four of these sets is said to be *complete.* Since the work of the flower is to produce seed, and seed-forming is due to the coöperation of stamens and pistils, or, as they are often called from their relation to the reproductive organs of spore-plants, *microsporophylls* and *macrosporophylls* (see Sect. 374), these are known as the *essential organs* (Fig. 138). The simplest possible pistil is a dwarfed and

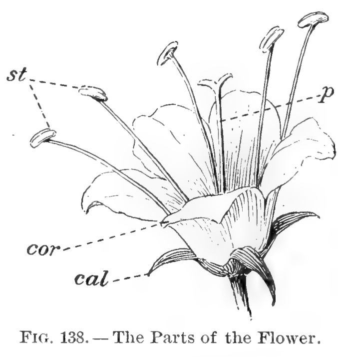


FIG. 138. — The Parts of the Flower. *cal*, calyx; *cor*, corolla; *st*, stamens; *p*, pistil.

[1] The flower of the waterleaf *Hydrophyllum canadense*, modified by the omission of the hairs on the stamens, is here given because it shows so plainly the relation of the parts.

greatly modified leaf (Sect. 222), adapted into a seed-bearing organ. Such a pistil may be one-seeded, as in Fig. 166, or several-seeded, as in the diagrammatic one (Fig. 150); it is called a *carpel.* The calyx and corolla are also known as the *floral envelopes.* Flowers which have the essential organs are called *perfect flowers.* They may, therefore, be perfect without being complete. Incomplete flowers with only one row of parts in the perianth are said to be *apetalous* (Fig. 139).

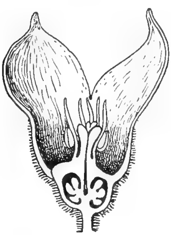
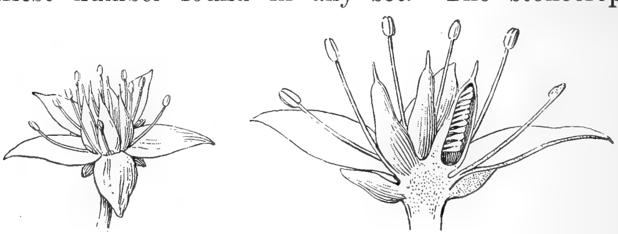


FIG. 139. — Apetalous Flower of (European) Wild Ginger.

209. Regular and Symmetrical Flowers. — A flower is *regular* if all the parts of the same set or circle are alike in size and shape, as in the stonecrop (Fig. 140). Such flowers as that of the violet, the monkshood, and the sweet pea (Fig. 141) are irregular. *Symmetrical* flowers are those whose calyx, corolla, circle of stamens, and set of carpels consist each of the same number of parts, or in which the number in every case is a multiple of the smallest number found in any set. The stonecrop is



I II

FIG. 140. — Flower of Stonecrop.
I, entire flower (magnified); II, vertical section (magnified).

symmetrical, since it has five sepals, five petals, ten stamens, and five carpels. Roses, mallows, and mignonette

are familiar examples of flowers which are unsymmetrical because they have a large, indefinite number of stamens; the portulaca is unsymmetrical, since it has two divisions of the calyx, five or six petals, and seven to twenty stamens.

210. The Receptacle. — The parts of the flower are borne on an expansion of the peduncle, called the *receptacle.* Usually, as in the flower of the grape (Fig. 250), this is only a slight enlargement of the peduncle, but in

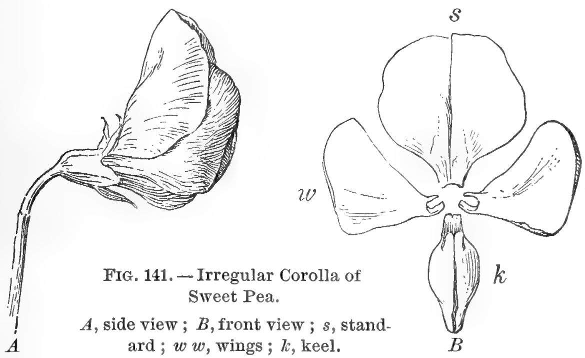


FIG. 141. — Irregular Corolla of Sweet Pea.

A, side view; *B*, front view; *s*, standard; *w w*, wings; *k*, keel.

the lotus and the magnolia the receptacle is of great size, particularly after the petals have fallen and the seed has ripened. The receptacle of the rose (Fig. 142) is hollow, and the pistils arise from its interior surface.

211. Imperfect or Separated Flowers. — The stamens and pistils may be produced in separate flowers, which are, of course, *imperfect.* This term does not imply that such flowers do their work any less perfectly than others, but only that they have not both kinds of essential organs. In the very simple imperfect flowers of the willow (Fig. 143) each flower of the catkin (Fig. 131) consists merely

of a pistil or a group of (usually two) stamens, springing from the axil of a small bract.

Staminate and pistillate flowers may be borne on different plants, as they are in the willow, or they may be borne on the same plant, as in the hickory and the hazel, among trees, or in the castor-oil plant, Indian corn, and the begonias. When staminate and pistillate flowers are borne on separate plants, such a plant is said to be *diœcious*, that is, of two households; when both kinds of flower appear on the same individual, the plant is said to be *monœcious*, that is, of one household.

212. Study of Imperfect Flowers. — Examine, draw, and describe the imperfect flowers of some of the following diœcious plants and one of the monœcious plants:[1]

Diœcious plants	early meadow rue. willow. poplar.
Monœcious plants	walnut, oak, chestnut. hickory, alder, beech. birch, hazel, begonia.

213. Union of Similar Parts of the Perianth. — The sepals may appear to join or *cohere* to form a calyx which is more or less entirely united into one piece, as in Figs. 139 and 148. In this case the calyx is said to be *gamosepalous*, that is, of wedded sepals. In the same way the corolla is frequently *gamopetalous*, as in Figs. 144–148. Frequently the border or *limb* of the calyx or corolla is more or less cut or lobed. In this case the projecting

[1] For figures or descriptions of these or allied flowers consult Gray's *Manual of Botany*, Emerson's *Trees and Shrubs of Massachusetts*, Newhall's *Trees of the Northern United States*, or Le Maout and Decaisne's *Traité Général de Botanique*.

portions of the limb are known as divisions, teeth, or lobes.[1] Special names of great use in accurately describing plants are given to a large number of forms of the gamopetalous corolla. Only a few of these names are here given, in connection with the figures.

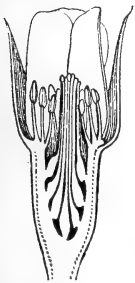


FIG. 142. A Rose, Longitudinal Section.

When the parts of either circle of the perianth are wholly unconnected with each other, that is, polysepalous or polypetalous, such parts are said to be *distinct.*

214. Parts of the Stamen and the Pistil. — The stamen usually consists of a hollow portion, the *anther* (Fig. 149, *a*), borne on a stalk called the *filament* (Fig. 149, *f*), which is often lacking. Inside the anther is a powdery or pasty substance called *pollen* or *microspores* (Sect. 374). The pistil usually consists of a small chamber, the *ovary*, which contains the *ovules*, *macrospores* (Sect. 374), or rudimentary seeds, a slender portion or stalk, called the *style*, and at the top of this a ridge, knob, or point called the *stigma*. These parts are all shown in Fig. 150. In many pistils the stigma is borne directly on the ovary.

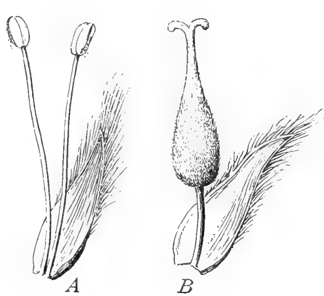


FIG. 143. — Flowers of Willow. (Magnified.)
A, staminate flower; *B*, pistillate flower.

215. Union of Stamens with Each Other. — Stamens may be wholly unconnected with

[1] It would not be safe to assume that the gamosepalous calyx or the gamopetalous corolla is really formed by the union of separate portions, but it is very convenient to speak of it as if it were.

each other or *distinct*, or they may cohere by their filaments into a single group, when they are said to be *monadelphous*, of one brotherhood (Fig. 151), into two groups (*diadelphous*) (Fig. 152), or into many groups. In some flowers the stamens are held together in a ring by their coherent anthers (Fig. 153).

FIG. 144. — Bell-Shaped Corolla of Bell-Flower (*Campanula*).

216. Union of Pistils. — The pistils may be entirely separate from each other, *distinct* and *simple*, as they are in the buttercup and the stonecrop, or several may join to form one *compound pistil* of more or less united carpels. In the latter case the union generally affects the ovaries, but often leaves the styles separate, or it may result in joining ovaries and styles, but leave the stigmas separate or at any rate lobed, so as to show of how many separate carpels the compound pistil is made up. Even when there is no external sign to show the compound nature of the pistil, it can usually be recognized from the study of a cross-section of the ovary.

FIG. 145. — Salver-Shaped Corolla of Jasmine. (Magnified.)

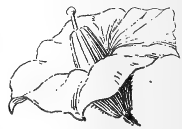


FIG. 146. Wheel-Shaped Corolla of Potato.

217. Cells of the Ovary; Placentas. — Compound ovaries are very commonly several-celled, that is, they consist of a number of

separate cells[1] or chambers, more scientifically known as *locules.* Fig. 154, *B*, shows a three-celled ovary seen in cross-section. The ovules are not borne indiscriminately by any part of the lining of the ovary. In one-celled pistils they frequently grow in a line running along one side of the ovary, as in the pea pod (Fig. 271). The ovule-bearing line is called a *placenta;* in compound pistils there are commonly as many placentas as there are

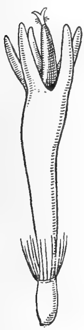


FIG. 147.—Tubular Corolla, from Head of Bachelor's Button.

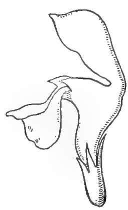


FIG. 148.—Labiate or Ringent Corolla of Dead Nettle.

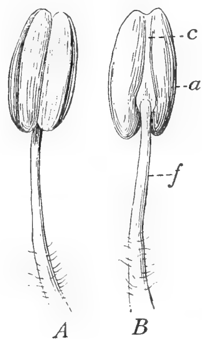


FIG. 149.—Parts of a Stamen.

A, front; *B*, back; *a*, anther; *c*, connective; *f*, filament.

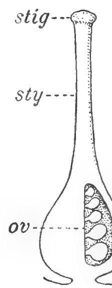


FIG. 150.—Parts of the Pistil.

ov, ovary.
sty, style.
stig, stigma.

separate pistils joined to make the compound one. Placentas on the wall of the ovary, like those in Fig. 154, *A*, are called *parietal placentas;* those which occur as at *B*, in the same figure, are said to be central, and those which, like the form represented in *C* of the same figure, consist of a column rising from the bottom of the ovary are called *free central placentas.*

[1] Notice that the word *cell* is here used in an entirely different sense from that in which it has been employed in the earlier chapters of this book. As applied to the ovary, it means a chamber or compartment.

218. Union of Separate Circles. — The members of one of the circles of floral organs may join those of another circle, thus becoming *adnate*, *adherent*, or *consolidated*.

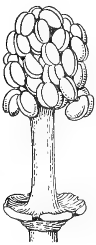


FIG. 151. Monadelphous Stamens of Mallow.

In Fig. 139 the calyx tube is adnate to the ovary. In this case the parts of the flower do not all appear to spring from the receptacle. Fig. 155 illustrates three common cases as regards insertion of the parts of the flower. In I they are all inserted on the receptacle, and the corolla and stamens are said to be *hypogynous*, that is, beneath the pistil. In II the petals and the stamens appear as if they had grown fast to the calyx for some distance, so that they surround the pistil, and they are therefore said to be *perigynous*, that is, around the pistil. In III all the parts are *free* or unconsolidated, except the petals and stamens; the stamens may be described as *epipetalous*, that is, growing on the petals.

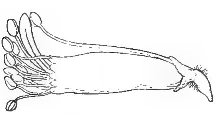


FIG. 152. — Diadelphous Stamens of Sweet Pea.

Sometimes some or all of the other parts stand upon the ovary, and such parts are said to be *epigynous*, that is, on the ovary, like the petals and stamens of the white water-lily (Fig. 156).

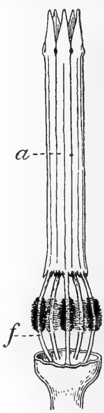


FIG. 153. — Stamens of a Thistle, with Anthers united into a Ring.

a, united anthers; *f*, filaments, bearded on the sides.

219. Floral Diagrams. — Sections (real or imaginary) through the flower lengthwise, like those of Fig. 155, help greatly in giving an accurate idea of the relative position of the floral organs. Still more

important in this way are cross-sections, which may be recorded in diagrams like those of Fig. 157.[1] In constructing such diagrams it will often be necessary to suppose some of the parts of the flower to be raised or lowered from their true position, so as to bring them into such relations that all could be cut by a single section. This would, for instance, be necessary in making a diagram for the cross-section of the flower

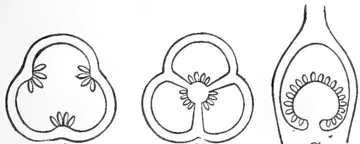


FIG. 154. — Principal Types of Placenta. *A*, parietal placenta ; *B*, central placenta ; *C*, free central placenta ; *A* and *B*, transverse sections ; *C*, longitudinal section.

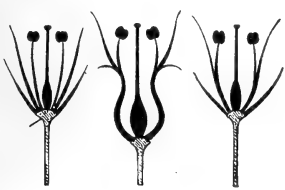


FIG. 155. — Insertion of the Floral Organs.

I, Hypogynous, all the other parts on the receptacle, beneath the pistil ; II, Perigynous, petals and stamens apparently growing out of the calyx, around the pistil ; III, corolla hypogynous, stamens epipetalous.

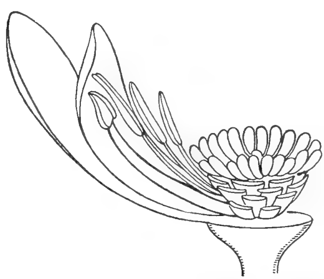


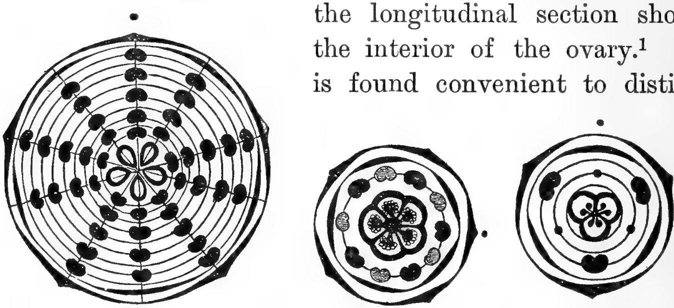
FIG. 156. — White Water-Lily. The inner petals and the stamens growing from the ovary.

of the white water-lily, of which a partial view of one side is shown in Fig. 156.[2]

[1] For floral diagrams see Le Maout and Decaisne's *Traité Général de Botanique*, or Eichler's *Blüthendiagramme*.

[2] It is best to begin practice on floral diagrams with flowers so firm and large that actual sections of them may be cut with ease and the relations of the parts in the section readily made out. The tulip is admirably adapted for this purpose.

Construct diagrams of the longitudinal section and the transverse section of several large flowers, following the method indicated in Figs. 155 and 157, but making the longitudinal section show the interior of the ovary.[1] It is found convenient to distinguish the sepals from the petals by representing the former with midribs. The diagrammatic symbol for a stamen stands for a cross-section of the anther, and that for the pistil is a section of the ovary. If any part is lacking in the flower (as in the case of flowers which have some antherless filaments) the missing or abortive organ may be indicated by a dot. In the diagram of the Iris Family (Fig. 157, III) the three dots inside the flower indicate the position of a second circle of stamens, found in most flowers of monocotyledons but *not* found in this family.



I II III

FIG. 157. — Diagram of Cross-Sections of Flowers.

I, columbine; II, heath family; III, iris family. In each diagram the dot alongside the main portion indicates a cross-section of the stem of the plant. In II every other stamen is more lightly shaded, because some plants of the heath family have five and some ten stamens.

[1] Among the many excellent early flowers for this purpose may be mentioned trillium, bloodroot, dogtooth violet, marsh marigold, buttercup, tulip tree, horse-chestnut, Jeffersonia, May-apple, cherry, apple, crocus, tulip, daffodil, primrose, wild ginger, cranesbill, locust, bluebell.

220. Review Summary of Chapter XV.[1]

Kinds of flowers as regards number of circles or sets of organs present	1. 2. 3. 4.
Kinds as regards numerical plan	1. 2.
Kinds as regards similarity of parts of the same circle	1. 2.
Parts of a stamen	1. 2.
Parts of a pistil	1. 2. 3.
Stamens as regards union with each other . . .	1. 2. 3. 4.
Pistils as regards union with each other	1. 2.
Degree of union of separate circles	

[1] Illustrate by sketches.

CHAPTER XVI

TRUE NATURE OF FLORAL ORGANS; DETAILS OF THEIR STRUCTURE; FERTILIZATION

221. The Flower a Shortened and greatly Modified Branch. — In Chapter VIII, the leaf-bud was explained as being an undeveloped branch, which in its growth would develop into a real branch (or a prolongation of the main stem). Now, since flower-buds appear regularly

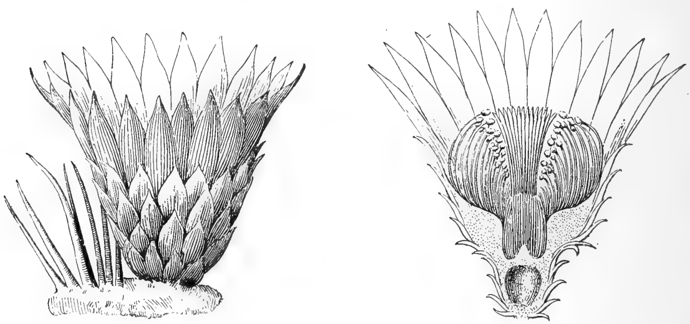


Fig. 158. — Transition from Bracts to Sepals in a Cactus Flower.

either in the axils of leaves or as terminal buds, there is reason to regard them as of similar nature to leaf-buds. This would imply that the receptacle corresponds to the axis of the bud shown in Fig. 86, and that the parts of the flower correspond to leaves. There is plenty of evidence that this is really true. Sepals frequently look very much like leaves, and in many cacti the bracts

about the flower are so sepal-like that it is impossible to tell where the bracts end and the sepals begin (Fig. 158). The same thing is true of sepals and petals in such flowers as the white water-lily. In this flower there is a remarkable series of intermediate steps, ranging all the way from petals, tipped with a bit of anther, through stamens with a broad petal-like filament, to regular stamens, as is shown in Fig. 159, *E*, *F*, *G*, *H*. The same thing is shown in

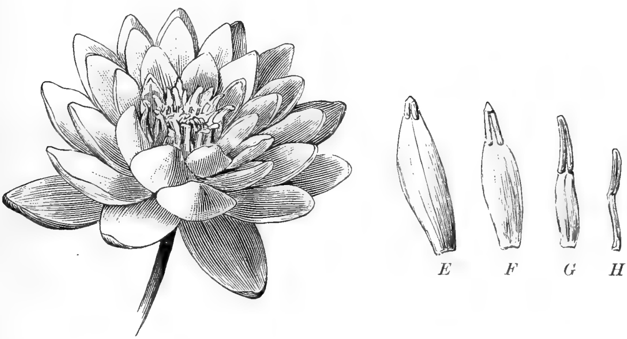


FIG. 159. — Transitions from Petals to Stamens in White Water-Lily.
E, *F*, *G*, *H*, various steps between petal and stamen.

many double roses. In completely double flowers all the *essential* organs are transformed by cultivation into petals. In the flowers of the cultivated double cherry the pistils occasionally take the form of small leaves, and some roses turn wholly into green leaves.

Summing up, then, we know that flowers are altered and shortened branches: (1) because flower-buds have as regards position, the same kind of origin as leaf-buds; (2) because all the intermediate steps are found between bracts, on the one hand, and stamens, on the other; (3)

because the essential organs are found to be replaced by petals or even by green leaves.

The fact that leaves should be so greatly modified as they are in flowers and given work to do wholly different from that of the other kinds of leaves so far studied need not strike one as exceptional. In many of the most highly developed plants below the seed-plants, organs corresponding to flowers are found, and these consist of modified leaves, set apart for the work of reproducing (Sect. 367).

222. Mode of Formation of Stamens and Pistils from Leaves. — It is hardly possible to state, until after Chapter XXIII has been studied, how stamens stand related to leaves.[1]

The simple pistil or *carpel* is supposed to be made on the plan of a leaf folded along the midrib until its margins touch, like the cherry leaf in Fig. 87. But the student must not understand by this statement that the little pistil leaf grows at first like an ordinary leaf and finally becomes folded in. The united leaf-margins near the tip would form the stigma, and the placenta would correspond to the same margins, rolled slightly inwards, extending along the inside of the inflated leaf-pouch. Place several such folded leaves upright about a common center, and their cross-section would be much like that of *B* in Fig. 154. Evidence that carpels are really formed in this way may be gained from the study of such fruits as that of the monkshood (Fig. 168), in which the ripe carpels may be seen to unfold into a shape much more leaf-like than that which they had while the pistil was maturing. What

[1] "The anther answers exactly to the spore-cases of the ferns and their allies, while the filament is a small specialized leaf to support it." For a fuller statement, see Potter and Warming's *Systematic Botany*, pp. 236, 237.

really occurs is this: the flower-bud, as soon as it has developed far enough to show the first rudiments of the essential organs, contains them in the form of minute knobs. These are developed from the tissues of the plant in the same manner as are the knobs in a leaf-bud, which afterwards become leaves (Fig. 87, II); but as growth and development progress in the flower-bud, its contents soon show themselves to be stamens and pistils (if the flower is a perfect one).

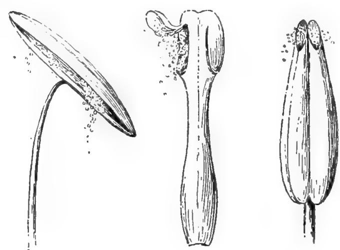


FIG. 160.—Modes of discharging Pollen.

I, by longitudinal slits in the anther-cells (amaryllis); II, by uplifted valves (barberry); III, by a pore at the top of each anther-lobe (nightshade).

223. The Anther and its Contents.—Some of the shapes of the anthers may be learned from Figs. 149 and 160.[1] The shape of the anther and the way in which it opens depend largely upon the way in which the pollen is to be discharged and how it is carried from flower to flower. The commonest method is to have the anther-cells split lengthwise, as in Fig. 160, I. A few anthers open by trap-doors like valves, as in II, and a larger number by little holes at the top, as in III.

The pollen in many plants with inconspicuous flowers, as the evergreen cone-bearing trees, the grasses, rushes, and sedges, is a fine, dry powder. In plants with showy flowers it is often somewhat sticky or pasty. The forms of pollen grains are extremely various. Fig. 161 will serve to furnish examples of some of the shapes which

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. II, pp. 86–95.

the grains assume; *c* in the latter figure is perhaps as common a form as any. Each pollen grain consists mainly of a single cell, and is covered by a moderately thick outer wall and a thin inner one. Its contents are thickish protoplasm, full of little opaque particles and usually containing grains of starch and little drops of oil. The knobs on the outer coat, as shown in Fig. 161 *b*, mark

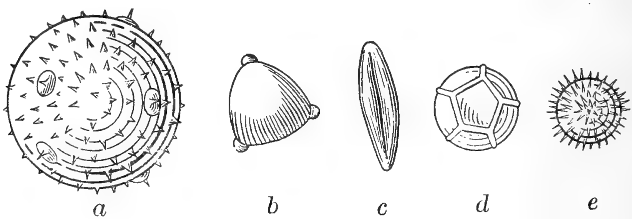


FIG. 161. — Pollen Grains. (Very greatly magnified.)
a, pumpkin; *b*, enchanter's nightshade; *c*, Albuca; *d*, pink; *e*, hibiscus.

the spots at which the inner coat of the grain is finally to burst through the outer one, pushing its way out in the form of a slender, thin-walled tube.[1]

224. The Formation of Pollen Tubes. — This can be studied in pollen grains which have lodged on the stigma and there been subjected to the action of its moist surface. It is, however, easier to cause the artificial production of the tubes.

EXPERIMENT XXXVIII

Production of Pollen Tubes. — Place a few drops of suitably diluted syrup with some fresh pollen in a concave cell ground in a microscope slide; cover with thin glass circle; place under a bell-glass, with a wet cloth or sponge, to prevent evaporation of the syrup, and set aside in a warm place, or merely put some pollen in syrup in a

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. II, pp. 95–104.

watch crystal under the bell-glass. Examine from time to time to note the appearance of the pollen tubes. Try several kinds of pollen if possible, using syrups of various strengths. The following kinds of pollen form tubes readily in syrups of the strengths indicated.

Tulip	1 to 3 per cent.
Narcissus	3 to 5 "
Cytisus canariensis (called Genista by florists)	15 "
Chinese primrose	10 "
Sweet pea [1]	10 to 15 "
Tropæolum [1]	15 "

225. Microscopical Structure of the Stigma and Style. — Under a moderate power of the microscope the stigma is seen to consist of cells set irregularly over the surface, and secreting a moist liquid to which the pollen grains adhere (Fig. 162). Beneath these superficial cells and running down through the style (if there is one) to the ovary is spongy parenchyma. In some pistils the pollen tube proceeds through the cell walls, which it softens by means of a substance which it exudes for that purpose. In other cases (Fig. 163) there is a canal or passage, along which the pollen tube travels on its way to the ovule.

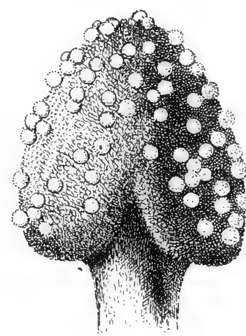


FIG. 162. — Stigma of Thorn-Apple (*Datura*) with Pollen. (Magnified.)

[1] The sweet-pea pollen and that of Tropæolum are easier to manage than any other kinds of which the author has personal knowledge. If a concaved slide is not available, the cover-glass may be propped up on bits of the thinnest broken cover-glasses. From presence of air or some other reason, the formation of pollen tubes often proceeds most rapidly just inside the margin of the cover-glass.

226. Fertilization. — By fertilization in seed-plants the botanist means the union of a generative cell from a pollen grain with that of an egg-cell at the apex of the *embryo sac* (Fig. 165). This process gives rise to a cell which contains material derived from the pollen and from the egg-cell. In a great many plants the pollen, in order to accomplish the most successful fertilization, must come from another plant of the same kind, not from the individual which bears the ovules that are being fertilized.

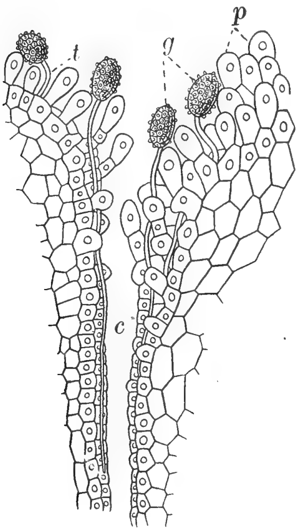


Fig. 163. — Pollen Grains producing Tubes, on Stigma of a Lily. (Much magnified.)

g, pollen grains; *t*, pollen tubes; *p*, papillæ of stigma; *c*, canal or passage running toward ovary.

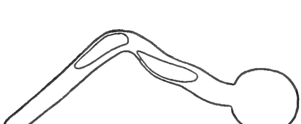


Fig. 164. — Pollen Grain of Snowflake (*Leucoium*) producing a Pollen Tube with Two Naked Generative Cells.

Pollen tubes begin to form soon after pollen grains lodge on the stigma. The time required for the process to begin varies in different kinds of plants, requiring in many cases twenty-four hours or more. The length of time needed for the pollen tube to make its way through the style to the ovary depends upon the length of the style and other conditions. In the crocus, which has a style several inches long, the descent takes from one to three days.

Finally the tube penetrates the opening at the apex of

the ovule m, in Fig. 165, reaches one of the cells shown at e, and transfers a generative cell into this egg-cell. The latter is thus enabled to divide and grow rapidly into an embryo. This the cell does by forming cell-walls and then increasing by continued subdivision, in much the same way in which the cells at the growing point near the tip of the root, or those of the cambium layer, subdivide.[1]

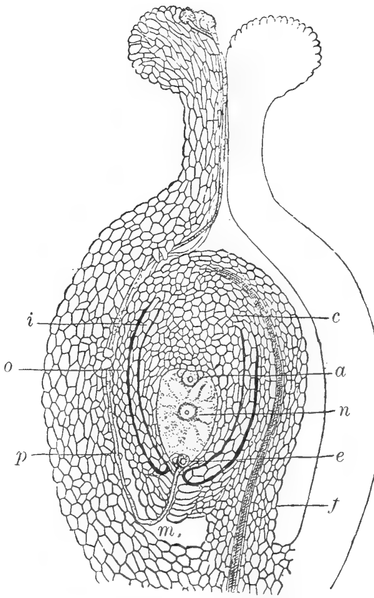


FIG. 165. — Diagrammatic Representation of Fertilization of an Ovule.

i, inner coating of ovule; o, outer coating of ovule; p, pollen tube, proceeding from one of the pollen grains on the stigma; c, the place where the two coats of the ovule blend. (The kind of ovule here shown is inverted, its opening m being at the bottom, and the stalk f adhering along one side of the ovule.) a to e, embryo sac, full of protoplasm; a, so-called antipodal cells of embryo sac; n, central nucleus of the embryo sac; e, nucleated cells, one of which, the egg-cell, receives the essential contents of the pollen tube; f, funiculus or stalk of ovule; m, opening into the ovule.

227. Nature of the Fertilizing Process. — The necessary feature of the process of fertilization is *the union of the essential contents of two cells to form a new one, from which the future plant is to spring.* This kind of union is found to occur in many cryptogams (Chapters XX–XXII), resulting in the production of a spore capable of growing into a complete plant like that which produced it.

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. II, pp. 401–420.

228. Number of Pollen Grains to Each Ovule. — Only one pollen tube is necessary to fertilize each ovule, but so many pollen grains are lost that plants produce many more of them than of ovules. The ratio, however, varies greatly. In the night-blooming cereus there are about 250,000 pollen grains for 30,000 ovules, or rather more than 8 to 1, while in the common garden wistaria there are about 7000 pollen grains to every ovule, and in Indian corn, the cone-bearing evergreens, and a multitude of other plants, many times more than 7000 to 1. These differences depend upon the mode in which the pollen is carried from the stamens to the pistil.

CHAPTER XVII

THE STUDY OF TYPICAL FRUITS

229. A Berry, the Tomato.[1] — Study the external form of the tomato, and make a sketch of it showing the persistent calyx and peduncle.

Cut a cross-section at about the middle of the tomato. Note the thickness of the epidermis (peel off a strip) and of the wall of the ovary. Note the number, size, form, and contents of the cells of the ovary. Observe the thickness and texture of the partitions between the cells. Sketch.

Note the attachments of the seeds to the placentas and the gelatinous, slippery coating of each seed.

The tomato is a typical berry, but its structure presents fewer points of interest than are found in some other fruits of the same general character, so the student will do well to spend a little more time on the examination of such fruits as the orange or the lemon.

230. A Hesperidium, the Lemon. — Procure a large lemon which is not withered, if possible one which still shows the remains of the calyx at the base of the fruit.

Note the color, general shape, surface, remains of the calyx, knob at portion formerly occupied by the stigma. Sketch the fruit about natural size. Examine the pitted surface of the rind with the magnifying glass and sketch it. Remove the bit of stem and dried-up calyx from the base of the fruit; observe, above the calyx, the knob or *disk* on which the pistil stood. Note with the magnifying glass and count the minute whitish raised knobs at the bottom of the saucer-shaped depression left by the removal of the disk. What are they?

[1] Fresh tomatoes, not too ripe, are to be used, or those which have been kept over from the previous summer in formalin solution. The very smallest varieties, such as are often sold for preserving, are as good for study as the larger kinds.

Make a transverse section of the lemon, not more than a fifth of the way down from the stigma end and note:

(1) The thick skin, pale yellow near the outside, white within.

(2) The more or less wedge-shaped divisions containing the juicy pulp of the fruit. These are the matured cells of the ovary; count these.

(3) The thin partition between the cells.

(4) The central column or axis of white pithy tissue.

(5) The location and attachment of any seeds that may be encountered in the section.

Make a sketch to illustrate these points, comparing it with Fig. 171.

Study the section with the magnifying glass and note the little spherical reservoirs near the outer part of the skin, which contain the oil of lemon which gives to lemon peel its characteristic smell and taste. Cut with the razor a thin slice from the surface of a lemon peel, some distance below the section, and at once examine the freshly cut surface with a magnifying glass to see the reservoirs, still containing oil, which, however, soon evaporates. On the cut surface of the pulp (in the original cross-section) note the tubes in which the juice is contained. These tubes are not cells, but their walls are built of cells. Cut a fresh section across the lemon, about midway of its length and sketch it, bringing out the same points which were shown in the previous one. The fact that the number of ovary cells in the fruit corresponds with the number of minute knobs in the depression at its base is due to the fact that these knobs mark the points at which fibro-vascular bundles passed from the peduncle into the cells of the fruit, carrying the sap by which the growth of the latter was maintained.

Note the toughness and thickness of the seed-coats. Taste the kernel of the seed.

Cut a very thin slice from the surface of the skin, mount in water, and examine with a medium power of the microscope. Sketch the cellular structure shown and compare it with the sketch of the corky layer of the bark of the potato tuber.

Of what use to the fruit is a corky layer in the skin? (See Sect. 453 for further questions.)

231. A Legume, the Bean-Pod.[1] — Lay the pod flat on the table and make a sketch of it, about natural size. Label *stigma, style, ovary, calyx, peduncle.*

Make a longitudinal section of the pod, at right angles to the plane in which it lay as first sketched, and make a sketch of the section, showing the partially developed seeds, the cavities in which they lie, and the solid portion of the pod between each bean and the next.

Split another pod, so as to leave all the beans lying undisturbed on one-half of it and sketch that half, showing the beans lying in their natural position and the *funiculus* or stalk by which each is attached to the *placenta;* compare Fig. 271.

Make a cross-section of another pod, through one of the beans, sketch the section, and label the placenta (formed by the united edges of the pistil leaf) and the midrib of the pistil leaf.

Break off sections of the pod and determine, by observing where the most stringy portions are found, where the fibro-vascular bundles are most numerous.

Examine some ripe pods of the preceding year,[2] and notice where the *dehiscence,* or splitting open of the pods, occurs, whether down the placental edge, *ventral suture,* the other edge, *dorsal suture,* or both.

232. An Akene, the Fruit of Dock. — Hold in the forceps a ripe fruit of any of the common kinds of dock,[3] and examine with the magnifying glass. Note the three dry, veiny, membranaceous sepals by which the fruit is enclosed. On the outside of one or more of the sepals is found a tubercle or thickened appendage which looks like a little seed or grain. Cut off the tubercles from several of the fruits, put these, with some uninjured ones, to float in a pan of water, and watch their behavior for several hours. What is apparently the use of the tubercle?

[1] Any species of bean (*Phaseolus*) will answer for this study. Specimens in the condition known at the markets as "shell-beans" would be best, but these are not obtainable in spring. Ordinary "string-beans" will do.

[2] Which may be passed round for that purpose. They should have been saved and dried the preceding autumn.

[3] *Rumex crispus, R. obtusifolius,* or *R. verticillatus.* This should have been gathered and dried the preceding summer.

Of what use are the sepals, after drying up? Why do the fruits cling to the plant long after ripening?

Carefully remove the sepals and examine the fruit within them. What is its color, size, and shape? Make a sketch of it as seen with the magnifying glass. Note the three tufted stigmas, attached by slender threads to the apex of the fruit. What does their tufted shape indicate?

What evidence is there that this seed-like fruit is not really a seed?

Make a cross-section of a fruit and notice whether the wall of the ovary can be seen, distinct from the seed-coats. Compare the dock fruit in this respect with the fruit of the buttercup, shown in Fig. 166. Such a fruit as either of these is called an *akene.*

CHAPTER XVIII

THE FRUIT[1]

233. What constitutes a Fruit. — It is not easy to make a short and simple definition of what botanists mean by the term *fruit*. It has very little to do with the popular use of the word. Briefly stated, the definition may be given as follows: *The fruit consists of the matured ovary and contents, together with any intimately connected parts.* Botanically speaking, the bur of beggar's ticks (Fig. 273), the three-cornered grain of buckwheat, or such true grains as wheat and oats, are as much fruits as is an apple or a peach.

The style or stigma sometimes remains as an important part of the fruit in the shape of a hook, as in the common hooked crowfoot; or in the shape of a plumed appendage, as in the virgin's bower, often called wild hops. The calyx may develop hooks, as in the agrimony, or plumes, as in the thistle, the dandelion, lettuce, and many other familiar plants. In the apple, pear, and very many berries, the calyx becomes enlarged and pulpy, often constituting the main bulk of the mature fruit. The receptacle not infrequently, as in the apple, forms a more or less important part of the fruit.

234. Indehiscent and Dehiscent Fruits. — All of the fruits considered in the next three sections are *indehiscent*,

[1] See Gray's *Structural Botany*, Chapter VII, also Kerner and Oliver's *Natural History of Plants*, Vol. II, pp. 427–438.

that is, they remain closed after ripening. *Dehiscent* fruits when ripe open in order to discharge their seeds. The three classes which immediately follow Sect. 237 belong to this division.

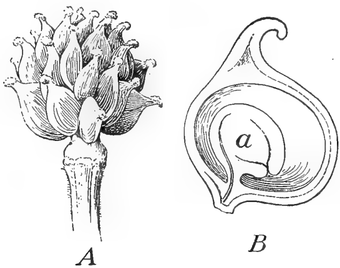


FIG. 166. — Akenes of a Buttercup. *A*, head of akenes; *B*, section of a single akene (magnified); *a*, seed.

235. The Akene. — The one-celled and one-seeded pistils of the buttercup, strawberry, and many other flowers, ripen into a little fruit called an *akene* (Fig. 166). Such fruits, from their small size, their dry consistency, and the fact that they never open, are usually taken for seeds by those who are not botanists.

In the group of plants to which the daisy, the sunflower, and the dandelion belong, the akenes consist of the ovary and the adherent calyx tube. The limb of the calyx is borne on the summit of many akenes, sometimes in the form of teeth, sometimes as a tuft of hairs or bristles (Fig. 267).

236. The Grain. — Grains, such as corn, wheat, oats, barley, rice, and so on, have the interior of the ovary completely filled by the seed, and the seed-coats and the wall of the ovary are firmly united, as shown in Fig. 6.

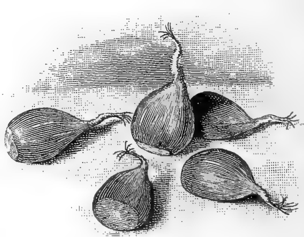


FIG. 167. — Chestnuts.

237. The Nut. — A nut (Fig. 167) is larger than an akene, usually has a harder shell, and commonly contains

a seed which springs from a single ovule of one cell of a compound ovary, which develops at the expense of all the other ovules. The chestnut-bur is a kind of involucre, and so is the acorn-cup. The name *nut* is often incorrectly applied in popular language; for example, the so-called Brazil-nut is really a large seed with a very hard testa.

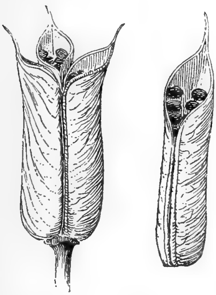


FIG. 168. — Group of Follicles and a Single Follicle of the Monkshood.

238. The Follicle. — One-celled, simple pistils, like those of the marsh marigold, the columbine, and a good many other plants, often produce a fruit which dehisces along a single suture, usually the ventral one. Such a fruit is called a *follicle* (Fig. 168).

239. The Legume. — A legume is a one-celled pod, formed by the maturing of a simple pistil, which dehisces along both of its sutures, as already seen in the case of the bean pod, and illustrated in Fig. 271.

240. The Capsule. — The dehiscent fruit formed by the ripening of a compound pistil is called a *capsule*. Such a fruit may be one-celled, as in the linear pod of the celandine (Fig. 271), or several-celled, as in the fruit of the poppy, the morning-glory, and the jimson weed (Fig. 271).

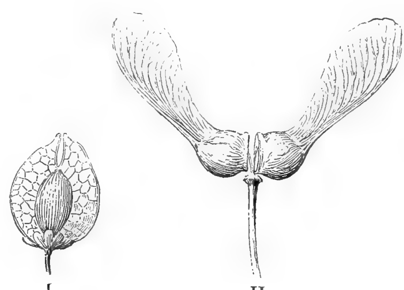


FIG. 169. — Winged Fruits.
I, elm; II, maple.

241. Dry Fruits and Fleshy Fruits. — In all the cases discussed or described in Sects. 238–240, the wall of the ovary (and the adherent calyx when present) ripen into tissues which are somewhat hard and dry. Often, however, these parts become developed into a juicy or fleshy mass by which the seed is surrounded; hence a general division of fruits into *dry fruits* and *fleshy fruits*.

242. The Stone-Fruit. — In the peach, apricot, plum, and cherry, the *pericarp* or wall of the ovary, during the process of ripening, becomes converted into two kinds of tissue, the outer portion pulpy and edible, the inner portion of almost stony hardness. In common language the hardened inner layer of the pericarp, enclosing the seed, is called the *stone* (Fig. 170), hence the name *stone-fruits*.

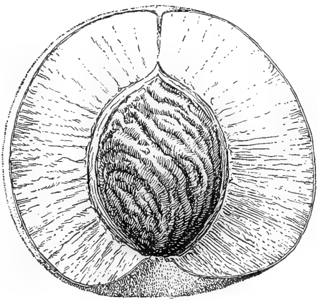


FIG. 170. — Peach. Longitudinal Section of Fruit.

243. The Pome. — The fruit of the apple, pear, and quince is called a *pome*. It consists of a several-celled ovary, — the seeds and the tough membrane surrounding them in the *core*, — enclosed by a fleshy, edible portion which makes up the main bulk of the fruit and is formed from the much-thickened calyx, with sometimes an enlarged receptacle. In the apple and the pear much of the fruit is receptacle.

244. The Pepo or Gourd-Fruit. — In the squash, pumpkin, and cucumber, the ripened ovary, together with the thickened adherent calyx, makes up a peculiar fruit (with a firm outer rind) known as the *pepo*. The relative bulk

of enlarged calyx and of ovary in such fruits is not always the same.

How does the amount of material derived from fleshy and thickened placentæ in the squash compare with that in the watermelon?

245. The Berry. — The berry proper, such as the tomato, grape, persimmon, gooseberry, currant, and so on, consists of a rather thin-skinned, one- to several-celled, *fleshy ovary* and its contents. In the first three cases above mentioned the calyx forms no part of the fruit, but it does in the last two, and in a great number of berries.

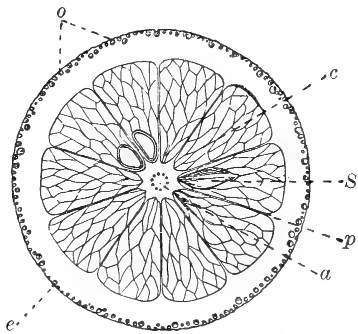


FIG. 171. — Cross-Section of an Orange.
a, axis of fruit with dots showing cut-off ends of fibro-vascular bundles; *p*, partition between cells of ovary; *S*, seed; *c*, cell of ovary, filled with a pulp composed of irregular tubes, full of juice; *o*, oil reservoirs near outer surface of rind; *e*, corky layer of epidermis.

The gourd-fruit and the *hesperidium*, such as the orange (Fig. 171), lemon, and lime, are merely decided modifications of the berry proper.

246. Aggregate Fruits. — The raspberry, blackberry (Fig. 172), and similar fruits consist of many carpels, each of which ripens into a part of a compound mass, which, for a time at least, clings to the receptacle. The whole is called an *aggregate fruit*.

To which one of the preceding classes does each unit of a blackberry or of a raspberry belong?

What is the most important difference in structure between a fully ripened raspberry and a blackberry?

247. Accessory Fruits and Multiple Fruits. — Not infrequently, as in the strawberry (Fig. 172), the main bulk of the so-called fruit consists neither of the ripened ovary nor its appendages. Such a combination is called an *accessory fruit.*

Examine with a magnifying glass the surface of a small, unripe strawberry, then that of a ripe one, and finally a section of a ripe one, and decide where the separate fruits of the strawberry are found, what kind of fruits they are, and of what the main bulk of the strawberry consists.

The fruits of two or more separate flowers may blend into a single mass, which is known as a *multiple fruit.* Perhaps the best-known edible examples of this are the

I II III

FIG. 172. — I, Strawberry; II, Raspberry; III, Mulberry.

mulberry (Fig. 172) and the pineapple. The last-named fruit is an excellent instance of the seedless condition which not infrequently results from long-continued cultivation.

248. Summary. — The student may find it easier to retain what knowledge he has gained in regard to fruits if he copies the following synopsis of the classification of fruits, and gives an example of each kind.

- Fruits
  - Composition
    - Simple.
    - Aggregate.
    - Accessory.
    - Multiple.
  - Texture
    - Fleshy
      - 1.
      - 2.
      - 3.
    - Stone
    - Dry
      - 1.
      - 2.
      - 3.
      - 4.
  - Mode of disseminating seed
    - Indehiscent
      - 1.
      - 2.
      - 3.
    - Dehiscent
      - 1.
      - 2.
      - 3.

CHAPTER XIX

THE CLASSIFICATION OF PLANTS [1]

249. Natural Groups of Plants. — One does not need to be a botanist in order to recognize the fact that plants naturally fall into groups which resemble each other pretty closely, that these groups may be combined into larger ones the members of which are somewhat alike, and so on. For example, all the bulb-forming spring buttercups [2] which grow in a particular field may be so much alike in leaf, flower, and fruit that the differences are hardly worth mentioning. The tall summer buttercups [3] resemble each other closely, but are decidedly different from the bulbous spring-flowering kind, and yet are enough like the latter to be ranked with them as buttercups. The yellow water-buttercups [4] resemble in their flowers the two kinds above mentioned, but differ from them greatly in habit of growth and in foliage, while still another, a very small-flowered kind,[5] might fail to be recognized as a buttercup at all.

The marsh marigold, the hepatica, the rue anemone, and the anemone all have a family resemblance to buttercups,[6] and the various anemones by themselves form another group like that of the buttercups.

[1] See Warming and Potter's *Systematic Botany*, Strasburger, Noll, Schenk, and Schimper's *Text-Book of Botany*, Part II, or Kerner and Oliver, Vol. II, pp. 616–790. [2] *R. bulbosus.* [3] *R. acris.* [4] *R. multifidus.* [5] *R. abortivus.*

[6] Fresh specimens or herbarium specimens will show this.

250. Genus and Species. — Such a group as that of the buttercups is called a *genus* (plural *genera*), while the various kinds of buttercups of which it is composed are called *species*. The scientific name of a plant is that of the genus followed by that of the species. The generic name begins with a capital, the specific does not, unless it is a substantive. After the name comes the abbreviation for the name of the botanist who is authority for it; thus the common elder is *Sambucus canadensis*, L., L. standing for Linnæus. Familiar examples of genera are the Violet genus, the Rose genus, the Clover genus, the Golden-rod genus, the Oak genus. The number of species in a genus is very various, — the Kentucky Coffee-tree genus contains only one species, while the Golden-rod genus comprises more than forty species in the northeastern United States alone.

251. Hybrids. — If the pollen of a plant of one species is placed on the stigma of a plant of the same genus but a different species, no fertilization will usually occur. In a large number of cases, however, the pistil will be fertilized, and the resulting seed will often produce a plant intermediate between the two parent forms. This process is called *hybridization*, and the resulting plant a *hybrid*. Many hybrid oaks have been found to occur in a state of nature, and hybrid forms of grapes, orchids, and other cultivated plants, are produced by horticulturists at will.

252. Varieties. — Oftentimes it is desirable to describe and give names to subdivisions of species. All the cultivated kinds of apple are reckoned as belonging to one species, but it is convenient to designate such varieties as the

Baldwin, the Bellflower, the Rambo, the Gravenstein, the Northern Spy, and so on. Very commonly varieties do not, as horticulturists say, "come true," that is to say, the seeds of any particular variety of apple not only are not sure to produce that variety, but they are nearly sure to produce a great number of widely different sorts. Varieties which will reproduce themselves from the seed, such as pop-corn, sweet corn, flint-corn, and so on, are called *races*.

Only long and careful study of plants themselves and of the principles of classification will enable any one to decide on the limits of the variety, species, or genus, that is, to determine what plants shall be included in a given group and what ones shall be classed elsewhere.

253. Order or Family. — Genera which resemble each other somewhat closely, like those discussed in Sect. 249, are classed together in one order or family. The particular genera above mentioned, together with a large number of others, combine to make up the Crowfoot family. In determining the classification of plants most points of structure are important, but the characteristics of the flower and fruit outrank others because they are more constant, since they vary less rapidly than the characteristics of roots, stems, and leaves do under changed conditions of soil, climate, or other surrounding circumstances. Mere size or habit of growth has nothing to do with the matter, so the botanist finds no difficulty in recognizing the strawberry plant and the apple tree as members of the same family.

This family affords excellent illustrations of the meaning of the terms *genus*, *species*, and so on. Put in a

tabular form, some of the subdivisions of the Rose family are as follows:

The Rose family includes (among many others):	Plum genus	Peach species (many varieties).	
		Garden plum species (many varieties).	
		Wild black cherry species.	
		Garden red cherry species (many varieties).	
	Rose genus	Dwarf wild rose species.	
		Sweet-brier species.	
		India rose species	Tea variety.
			Pompon variety, etc.
		Damask rose species.	
	Pear genus	Pear species	Seckel variety.
			Bartlett variety.
			Sheldon variety, etc.
		Apple species	Baldwin variety.
			Greening variety.
			Bellflower variety.
			Northern Spy variety, etc.

254. Grouping of Families. — Families are assembled into *classes*, and these again into larger *groups*. The details of the entire plan of classification are too complicated for any but professional botanists to master, but an outline of the scheme may be given in small space.

The entire vegetable kingdom is divided into two great divisions, the first consisting of *cryptogams* or spore-plants, the second of *phanerogams* or seed-plants. Here the relations of the various subdivisions may best be shown by a table.[1]

[1] This is, of course, only for consultation, not to be committed to memory.

255. Table of the Classification of the Vegetable Kingdom.

Division	Group	Class	
DIVISION I CRYPTOGAMS OR SPORE-PLANTS	GROUP I MYXOTHALLOPHYTES or *plasmodial plants*	CLASS	*Myxogasteres*, Common slime-fungi.
	GROUP II THALLOPHYTES or *leafless cellular cryptogams*[1]	CLASS 1.	*Schizomycetes*, Bacteria.
		" 2.	*Schizophyceæ*, Fission-plants.
		" 3.	*Bacillariales*, Diatoms.
		" 4.	*Conjugatæ*, Desmids and pond-scums.
		" 5.	*Chlorophyceæ*, Green algæ.
		" 6.	*Phæophyceæ*, Brown algæ.
		" 7.	*Rhodophyceæ*, Red algæ.
		" 8.	*Phycomycetes*, Moulds, etc.
		" 9.	*Basidiomycetes*, Mildews, rusts, and toadstools.
		" 10.	*Ascomycetes*, Yeasts, truffles, etc.
		COLLATERAL CLASS.	*Lichenes* — Algæ and fungi leading a life in partnership, the combination known as a *lichen*.
	GROUP III BRYOPHYTES or *moss-like plants*	CLASS 1.	*Hepaticæ*, Liverworts.
		" 2.	*Musci*, True mosses.
	GROUP IV PTERIDOPHYTES or *fern-like plants*	CLASS 1.	*Filicales*, Ferns.
		" 2.	*Equisetales*, Scouring rushes.
		" 3.	*Lycopodiales*, Club mosses.

[1] Classes 3–7 inclusive of the thallophytes are often placed in a subgroup known as *algæ*, and 8–10 inclusive in another subgroup, *fungi*.

DIVISION II PHANEROGAMS OR SEED-PLANTS	CLASS I GYMNOSPERMS or *seed-plants with naked ovaries,* such as pines, spruces, cedars, and many other evergreen trees.	
	CLASS II ANGIOSPERMS or *seed-plants with closed ovaries*	SUBCLASS I MONOCOTYLEDONOUS PLANTS SUBCLASS II DICOTYLEDONOUS PLANTS

256. The Groups of Cryptogams. — The student is not to suppose that the arrangement of cryptogams into the four great groups given in the preceding table is the only way in which they could be classed. It is simply one way of dividing up the enormous number of spore-bearing plants into sections, each designated by marked characteristics of its own. But the amount of difference between one group and another is not always necessarily the same. The pteridophytes and the bryophytes resemble each other much more closely than the latter do the thallophytes, while the myxothallophytes are but little like other plants and it is extremely probable that they are really animals.

The classes given in the table do not embrace all known cryptogams, but only those of which one or more representatives are described or designated for study in this book. Lichens in one sense hardly form a class, but it is most convenient to assemble them under a head by themselves, on account of their extraordinary mode of life, a partnership between algæ and fungi.

257. The Classes of Seed-Plants. — The gymnosperms are much less highly developed than other seed-plants.

The angiosperms constitute the great majority of seed-plants (or, as they have been more commonly called, flowering plants). Only one family of gymnosperms (the *Coniferæ*) is described in Part III of this book, though there are other families of great interest to the botanist, but with no representatives growing wild in the Northern United States.

When people who are not botanists speak of plants they nearly always mean angiosperms. This class is more interesting to people at large than any other, not only on account of the comparatively large size and the conspicuousness of the members of many families, but also on account of the attractiveness of the flowers and fruit of many. Almost all of the book which precedes the present chapter (except Chapter XII) has been occupied with seed-plants.

Seed-plants of both classes frequently offer striking examples of adaptation to the conditions under which they live, and these adaptations have lately received much study, and are now treated as a separate department of botany (see Part II).

CHAPTER XX

TYPES OF CRYPTOGAMS; THALLOPHYTES

258. The Group Thallophytes. — Under this head are classed all the multitude of cryptogams which have a plant-body without true roots, stems, or leaves. Such a plant-body is called a *thallus.* In its simplest form it consists of a portion of protoplasm not enclosed in a cell-wall and without much of any physiological division of labor among its parts (Fig. 125). Only a little less simple are such enclosed cells as that of *Pleurococcus* (Sect. 278) or one of the segments of *Oscillatoria* (Sect. 268). The most complex thallophytes, such as the higher algæ and fungi, have parts definitely set aside for absorption of food and for reproduction. The latter is sometimes accomplished by more than one process and is occasionally aided by some provision for scattering the reproductive bodies or *spores* about when they are mature.

259. Spores. — Before beginning the study of spore-plants it is well for the student to know what a spore is. *A spore is a cell which becomes free and capable of developing into a new plant.* Spores are produced in one of two ways: either *asexually*, from the protoplasm of some part of the plant (often a specialized spore-producing portion), or *sexually*, by the combination of two masses of protoplasm, from two separate plants, or from different parts of the same plant.

Asexually produced spores are sometimes formed, each by the condensation of the protoplasm of a single cell, as shown in Fig. 174, *E*. They are also formed by the contents of spore-cases breaking up into many spores (Fig. 173, *B*; Fig. 210, *D*). Spores are sometimes produced by the spontaneous division of a mass of protoplasm into a small definite number of segments (Fig. 188, *t*). Spores which have the power of moving (swimming) freely are known as *zoöspores* (Fig. 179, *B*).

Sexually produced spores are formed in many ways. One of the simplest modes is that shown in Fig. 178, resulting in *zygospores*. Other methods are illustrated in Figs. 185 and 187.[1]

THE STUDY OF SLIME MOULDS[2]

260. Occurrence. — Slime moulds occur in greenhouses, in tan-yards, or on old logs and decaying leaves in woods. They may be cultivated in the laboratory.

They have been described in their vegetative condition on page 179.

261. Examination with the Magnifying Glass. — *Stemonitis* is one of the most available genera to illustrate the fruiting of slime moulds. At maturity the motile protoplasm of the vegetative stage quickly transforms itself into numerous sporangia or spore-cases with dust-like spores. With the naked eye and with a magnifying glass note the color, form, and feathery appearance of the spore-case of *Stemonitis*. The outer wall disappears at an early stage, leaving only an inner structure and spores. Sketch the general outline under a magnifying glass.

262. Examination with the Microscope. — With a low power of the microscope sketch the network of branching hairs which compose the structure of the sporangium. Note the presence or absence

[1] See Vine's *Student's Text-Book of Botany*, pp. 68–71.

[2] This should logically precede Sect. 258.

of a central column. Have any of the branches free tips? With a power of 250 or more examine the spores. A much higher power may be used to advantage. Describe the surface of the spore.

THE STUDY OF BACTERIA

263. Occurrence. — "Bacteria may occur anywhere but not everywhere." In water, air, soil, and almost any organic substance, living

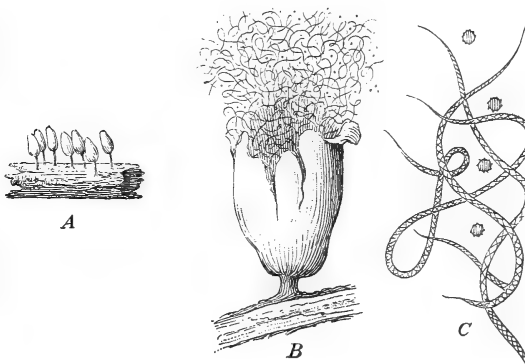


FIG. 173. — Spore-Cases of Slime Moulds.

A, a group of spore-cases of *Arcyria*; *B*, a spore-case of *Trichia*, bursting open and exposing its spores to the wind, × 20; *C*, threads of the same, with spores between them, × 250.

or dead, some species of plant belonging to the group *Bacteria* may occur. A small bunch of hay placed in a tumbler of water will, at a suitable temperature, yield an abundant crop in a few days or hours. Raw peas or beans soaked for a week or two in water in a warm place will afford a plentiful supply.

264. Cultures. — Pure cultures of bacteria are commonly made in some preparation of gelatine in sterilized test-tubes. Boiled potatoes serve a good purpose for simple (but usually not pure) cultures.

Select a few small roundish potatoes with skins entire and boil in water for a sufficient time to cook them through. Cut them in halves with a knife well scalded or *sterilized*, *i.e.*, freed from all living

organisms in a flame, and lay each on a saucer, with cut surface up, covering each with a glass tumbler. The tumblers and saucers should be well scalded or kept in boiling water for half an hour and used without wiping. Sterilization may be improved by baking them in an oven for an hour.

265. Inoculation. — The culture media prepared as above may now be inoculated. Uncover them only when necessary and quickly replace the cover. Scrape a little material from the teeth, tongue, kitchen sink, floor of house or schoolroom, or any other place you may desire to investigate. With the point of a knife blade or a needle sterilized in a flame, inoculate a particle of the material to be cultivated into the surface of one of the potatoes. Several cultures

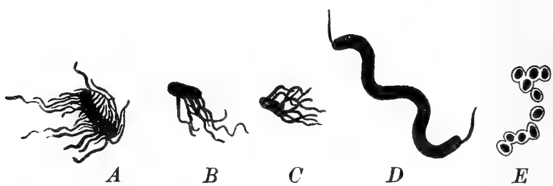


FIG. 174. — Bacteria stained to show Cilia.

A, *Bacillus subtilis*; *B*, *Bacillus typhi* (the bacillus of typhoid fever); *C*, *Bacillus tetani* (the bacillus which causes lockjaw); *D*, *Spirillum undula*; *E*, *Bacillus tetani* forming spores. (All five are magnified 1000 diameters.)

may be made in this way and one or more left uninoculated as checks. Another may be left uncovered in the air for half an hour. Others may be made with uncovered potatoes. Number each culture and keep a numbered record.

Keep watch of the cultures, looking at them daily or oftener. As soon as any change is noticed on the surface of a culture, make a descriptive note of it and continue to record the changes which are seen. Note the color of the areas of growth, their size, outline, elevation above the surface, and any indications of wateriness. Any growth showing peculiar colors or other characters of special interest may be inoculated into freshly prepared culture media, using any additional precautions that are practicable to guard against contamination.

266. Microscopic Examination. — Examine some of the cultures. Place a particle of the growth on a slide, dilute it with a drop of clear water, and place a cover-glass over it. Examine with the highest obtainable power of the microscope, at least $\frac{1}{6}$ in. objective. Note the forms and movements, also the sizes if practicable, of any bacteria that are found.

THE STUDY OF OSCILLATORIA[1]

267. Occurrence. — *Oscillatoria* may occur floating in stagnant water or on damp soil in ditches, roadsides, dooryards, paths, or pots in greenhouses. Other nearly related plants occur on surfaces of ponds sometimes covering considerable areas or adhering in small spheres to submerged vegetation. Algæ of this class are particularly noxious in water supplies, as they partake of the nature of bacteria, to which they are related.

268. Examination with the Microscope. — After washing a particle of *Oscillatoria* material in a drop of water to remove as much of the earth as possible, place it in a clean drop of water, pull to shreds with needles, cover, and examine under a power of 200 or more diameters.

Note the color and compare it with chlorophyll green.

The filament is not one plant, but each of the cells which compose it is one plant. They are packed together in the filament like coins and sometimes may be found separating singly. The usual mode of reproduction is by the separation of a number of adhering cells as a short filament from one end of a longer one, and this increases in length by the dividing of its individual cells.

269. Movement. — At ordinary temperatures, favorable to growth, movement may be observed in the filaments. Describe the movement. What has it to do with the name of the plant?

[1] A genus of the class *Schizophyceæ*.

THE STUDY OF DIATOMS

270. Occurrence. — Diatoms of different species may be found in sediment in water in various kinds of places or mixed with or adhering to fresh-water or marine algæ, in ponds and ditches or on sand or earth at the bottom of clear brooks. In the last place they may be detected with the eye, forming a yellowish coloring. They may often be obtained by straining hydrant water. Where diatoms have been very abundant their remains sometimes form beds of rock, and fossil diatoms compose some of the polishing powders of commerce.

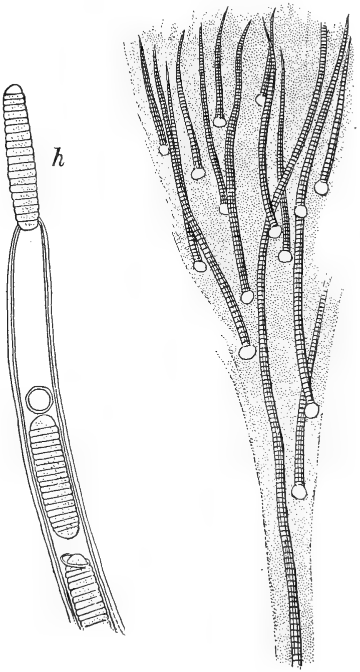


FIG. 175. — *Schizophyceæ.*
A, a filament of *Calothrix*, reproducing by *hormogonia*, *h*, segmented portions which escape from the sheath of the filament; *B*, *Rivularia*. (Both *A* and *B* greatly magnified.)

271. Microscopical Examination of Diatoms. — Place a drop of water containing diatoms on a slide and put a cover-glass over it. Examine with a power of 200 or more diameters. Diatoms occur singly, resembling triangles, wheels, boats, rods, and a great variety of other forms (Fig. 176), or adhering in long bands, as spokes of a wheel, etc. The boat-shaped kinds are among the commonest. The color of the contents is yellowish. The cell-wall is encrusted with a shell of silica whose surface is covered with beautiful markings, dots or lines, which are conspicuous in some species, in others so minute that the most powerful microscopes are required to detect them. By boiling

in nitric acid, the cellulose wall and its contents may be destroyed and the markings of the siliceous shell more easily observed. Each diatom consists of a single cell.

272. Movements of Diatoms. — Living diatoms exhibit a peculiar power of movement. In the boat-shaped species the movement is much like that of a row-boat, forward or backward.

THE STUDY OF SPIROGYRA

273. Occurrence. — *Spirogyra*, one of the plants commonly known as pond-scum, or "frog-spit," occurs widely distributed throughout the country in ponds, springs, and clear streams. It is of a green or yellowish-green color, and in sunny weather usually floats on or near the surface of the water, buoyed up by the numerous oxygen bubbles which it sets free. It may be found flourishing in unfrozen springs, even in midwinter.

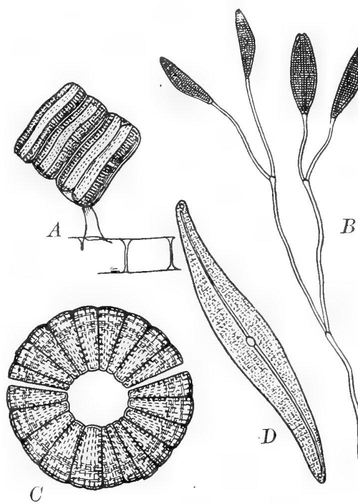


FIG. 176. — A Group of Diatoms.

A, Achnanthes; B, Cocconema; C, Meridion; D, Pleurosigma.

274. Examination with the Magnifying Glass.[1] — Float a little of the material in a white plate, using just water enough to cover the bottom of the latter. Study with the magnifying glass and note the green color of the threads and their great length as compared with their thickness. Are all the filaments about equal to each other in diameter?

Handle a mass of the material and describe how it feels between the fingers.

275. Examination with the Microscope. — Mount in water under a large cover-glass and examine first with a power of about 100

[1] Consult Huxley's *Biology* and Spalding's *Introduction to Botany*.

diameters, then with a power of 200 diameters or more. Note the structure of the filaments. Of what is each made up? Compare with the structure of *Oscillatoria.*

Move the slide so as to trace the whole length of several filaments, and, if the unbroken end of one can be found, study and sketch it.

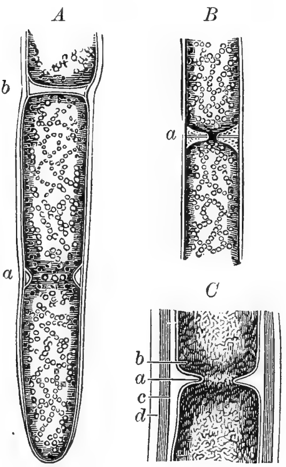


FIG. 177.—Process of Cell-Multiplication in a Species of Pond-Scum. (Considerably magnified.)

A, portion of a filament partly separated at *a* and completely so at *b*; *B*, separation nearly completed, a new partition of cellulose formed at *a*; *C*, another portion more magnified, showing mucous covering *d*, general cell-wall *c*, and a delicate membrane *a*, which covers the cell-contents *b*.

Study with the higher power a single cell of one of the larger filaments and ascertain the details of structure. Try to discover, by focusing, the exact shape of the cell. How do you know that the cells are not flat? Count the bands of chlorophyll. The number of bands is an important characteristic in distinguishing one species from another.

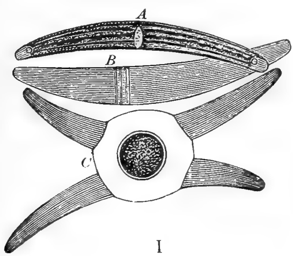
Run in five-per-cent salt solution at one edge of the cover-glass (withdrawing water from the other edge with a bit of blotting paper). If any change in the appearance of the cell becomes evident, make a sketch to show it. What has happened to the cell-contents? Explain the cause of the change by reference to what you know of osmose.

On a freshly mounted slide run under the cover-glass iodine solution, a little at a time, and note its action on the nucleus. Is any starch shown to be present? If so, just how is it distributed through the cell?

276. Reproduction of Spirogyra.—The reproductive process in *Spirogyra* is of two kinds, the simplest being a process of *fission*, or cell-division. The nucleus undergoes a very complicated series of transformations, which result in the division of the protoplasmic contents of a cell into two independent portions, each of which is at length surrounded by a complete cell-wall of its own. In Fig. 176

the division of the protoplasm and formation of a partition of cellulose in a kind of pond-scum are shown, but the nucleus and its changes are not represented.

Another kind of reproduction, namely by *conjugation*, is found in *Spirogyra*. This process in its simplest form is found in such unicellular plants as the desmids (Fig. 178). Two cells (apparently precisely alike) come in contact, undergo a thinning-down or absorptive process in the cell-walls at the point of contact, and finally blend their protoplasmic cell-contents, as shown in the figure, to form a mass known as a *spore*, or more accurately a *zygospore*, from which, after



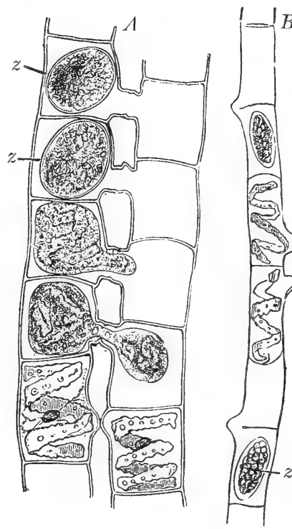


FIG. 178.—Conjugation of Cells of Green Algæ. (Much magnified.)

I. Conjugation of Desmids. *A*, a single plant in its ordinary condition; *B*, empty cell-wall of another individual; *C*, conjugation of two individuals to form a spore by union of their cell-contents.

II. Conjugation of *Spirogyra*. *A*, two filaments of *Spirogyra* side by side, with the contents of adjacent cells uniting to form spores, *z*. At the bottom of the figure the process is shown as beginning at the top as completed, and the cells of one filament emptied; *B*, a single filament of another kind of *Spirogyra*, containing two spores, one lettered *z*. (*A* magnified 240 diameters, *B* 150 diameters.)

a period of rest, a new individual develops. In *Spirogyra* each cell of the filament appears to be an individual and can conjugate like the one-celled desmids. It is not easy to watch the process, since the spore-formation takes place at night. It is possible,

however, to retard the occurrence of conjugation by leaving the *Spirogyra* filaments in very cold water over night, and in this way the successive steps of the conjugating process may be studied by daylight. In such ways the series of phenomena shown in Fig. 178, II, has been accurately followed. If the student cannot follow these operations under the microscope, he may, at least, by looking over the yellower portions of a mass of *Spirogyra* find threads containing fully formed zygospores, like those shown in *B*, Fig. 178.

THE STUDY OF PLEUROCOCCUS

277. Occurrence. — *Pleurococcus* may be found on old fences, roofs, and many similar places, particularly on the bark of the north side of trees. The individual plants cannot be detected by the naked eye, but when grouped in masses they form a powdery green covering over indefinite areas of bark. Plenty are seen where it is moist.

278. Microscopical Examination of Pleurococcus. — Scrape a minute quantity of *Pleurococcus* from a specimen on bark, place it in a drop of water on a slide, distributing it slightly in the water, lay on it a cover-glass and examine with a power of 200 or more diameters. Sketch with the *camera lucida* one of the largest cells, some of intermediate size, and one of the smallest, beside several divisions of the stage micrometer.

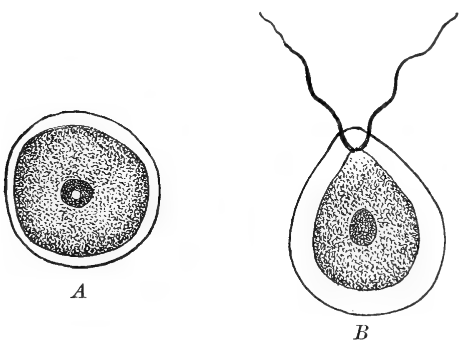


FIG. 179. — Two Cells of *Protococcus*. (Greatly magnified.)

A, a spherical cell of the still form; *B*, a motile cell with its protoplasm enclosed in a loose cell-wall and provided with two cilia.

Note the clearly defined cell-wall of cellulose, enclosing the protoplasmic contents, usually green throughout. Do any cells show a nucleus like that in Fig. 179, *A*?

Test the cells with iodine solution for starch.

Note that in reproduction the cell-contents in many individuals has divided into two parts which become separated from each other by a cellulose partition. Each of these again divides, and the process continues until thirty-two or more cells may be found in one mass or they may fall apart at an earlier stage.

279. Nutrition of Pleurococcus. — *Pleurococcus* can flourish only with an abundance of light and moisture. In daylight it can absorb carbon dioxide and fix carbon (giving off the oxygen at the same time as bubbles of oxygen) and can assimilate mineral substances. It is a capital example of an individual cell capable of independent existence.

280. Motile Forms. — No motile form is known in *Pleurococcus*. *Hœmatoccus*, often known as *Protococcus* (Fig. 179), is a better object for study than *Pleurococcus*. It may sometimes be found in water of stagnant pools, particularly those which contain the drainage of barnyards or manure-heaps, in mud at the bottom of eaves-troughs, in barrels containing rain-water, or in water standing in cavities in logs or stumps. Its presence is indicated by a greenish or sometimes by a reddish color. It is sometimes found in an actively swimming condition, in which case each cell is called a *zoöspore*.

THE STUDY OF VAUCHERIA

281. Occurrence. — Species of *Vaucheria* are found in ponds, streams, and pools, immersed or floating like *Spirogyra* and at all seasons may be sought in greenhouses, where they grow on the moist earth of beds and pots, forming a green felt.

282. Examination with the Magnifying Glass. — The magnifying glass will show the growth of *Vaucheria* to consist of numerous green filaments similar to those of *Spirogyra*. Select a small portion and spread out the filaments carefully in a drop of water on a slide. Does the glass reveal any indications of cross-partitions, of branching, or of fruiting organs as short lateral branches? Does it show the form or arrangement of the green coloring matter?

283. Examination with the Microscope. — Prepare as directed for the magnifying glass and place a cover-glass over the preparation, with sufficient water. With the lowest power observe the

continuity of the cell-cavity and (in young plants growing on soil) search for root-like portions, in those growing in water for branching portions, and fruiting organs in the form of swellings or short lateral branches.

With a power of about thirty to sixty diameters sketch a selected plant of moderate extent as nearly complete as possible or else

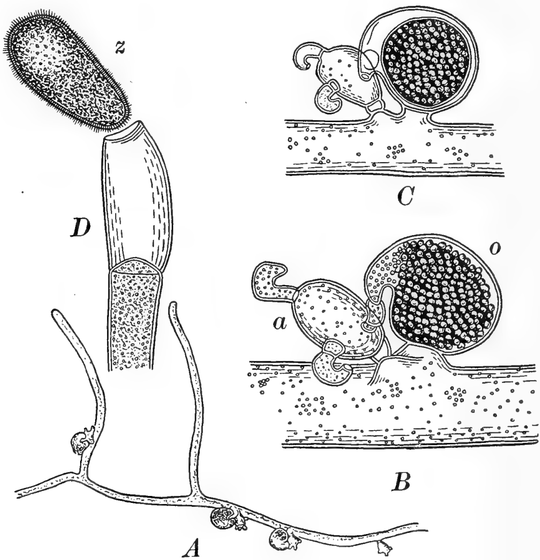


FIG. 180.— *Vaucheria synandra.*

A, a filament with archegonia and antheridia (considerably magnified); *B*, part of same much more highly magnified; *o*, oögonium; *a*, antheridium; *C*, a later stage of *B*; *D*, end of a filament with a zoöspore, *z*, escaping (highly magnified).

sketch a portion showing the branching and a root-like portion. Note and indicate the absence or presence and arrangement of chlorophyll. Can *Vaucheria* probably use carbon dioxide?

284. Reproduction in Vaucheria. — Make an outline sketch of fruiting organs, if found. See if any filaments can be found with the contents massing or escaping at the tips. In some species

zoöspores are formed in this way, having their entire surface clothed with cilia. They are the largest motile cells known. In other species a portion of the filament is separated and cut off by a cell-wall. Such spores soon germinate and may be found in various stages of growth. They often serve for propagation through several generations before spores are produced by fertilization.

With a power of about 200 diameters sketch a portion of a filament to show the form and location of chlorophyll. Sketch the fruiting organs in detail, if any can be found.[1]

Antheridia and oögonia are formed near together on the same filament. The antheridium is a cell forming the terminal portion of a short branch, which is rather slender, straight or curved. Its contents form numerous minute antherozoids, each with two cilia. The cilia can be seen only with great difficulty, if at all, but their presence is indicated by their active movements.

The oögonium is a short, somewhat spheroidal branch separated by a cross-partition at the base. The cell-wall becomes ruptured at the tip, allowing the entrance of the antherozoids by which it is fertilized. After fertilization a cell-wall is formed about the oösphere, and it matures as an oöspore and enters upon a period of rest.

THE STUDY OF NITELLA

285. Occurrence. — *Nitella* is a green plant growing attached to the bottom of ponds and streams, usually in shallow water. It is not common everywhere but is widely distributed. *Chara* is similar and may be used as a substitute but is more complicated.

286. General Aspect. — With the naked eye and a magnifying glass note the general aspect of *Nitella*, the length of the stem-like portions, from the root-like parts to the tip, the length of some of the joints (internodes), the arrangement of leaf-like and branch-like portions.

287. Protoplasm. — Examine the cells of stems or leaves under a low power. Select a vigorous cell of moderate size and examine

[1] Goebel states that the formation of the fruiting organs begins in the evening, is completed the next morning, and that fertilization takes place during the day between ten and four o'clock.

under a power of 200 or more diameters. Select the terminal cell of the leaf if *Chara* is used. The protoplasm is nearly colorless but usually contains bodies which can be seen moving in the current of protoplasm. The protoplasm will show normal activity at the temperature of a comfortable living room. By focusing, see if the current of protoplasm can be detected moving in more than one direction.

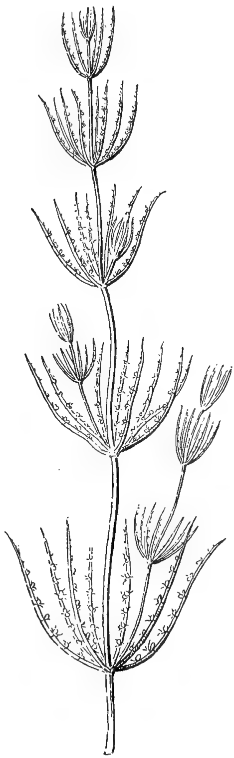


FIG. 181. — End of a Main Shoot of *Chara*. (About natural size.)

Note the form and arrangement of the chlorophyll and any places lacking chlorophyll, and see if you can tell whether the arrangement has any relation to the current of protoplasm. With a low power trace the course in several cells. How many cells constitute each internode of *Nitella?* If *Chara* is used, internodes will be found to be covered with a layer of many corticating cells. Under a high power compare the general structure of node and internode and see if the attachment of leaves and branches can be clearly determined. Compare the tip of a leaf with the tip of a stem or branch if the material permits. Are the fruiting organs produced on the stems or the leaves?

288. Antheridia. — The antheridia are globular bodies, bearing male fertilizing cells and becoming red at maturity (Fig. 182). Eight cells compose the outer wall. They have radial lines indicating folds and join one another by irregular sutures. Note a round spot in the middle of each cell which marks the point of attachment within of the stalk on which antherozoid-producing cells are borne.

289. Oögonia. — The egg-shaped fruits, known as *oögonia* (Fig. 182), are borne near the antheridia in monœcious species. Count the number of pointed cells which constitute the "crown" of the fruit. Does each tip consist of one or two short cells? Examine

the surface of the enveloping cells which enclose the spore. What is their number and form? What is their relation to the cells forming the crown? Focus so as to see the large egg-cell (*oösphere* or *oöspore*) which constitutes the center of the fruit. Can you determine anything regarding its contents?

Search for young oögonia and if practicable describe and draw them in several stages of development. Their structure can be seen much more easily than that of the antheridia. Make drawings to illustrate various details of structure.

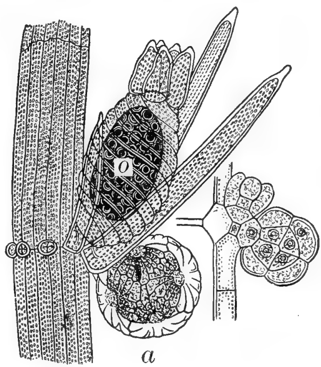


FIG. 182. — Part of a Leaf of Fig. 181. (Considerably magnified.)

a, antheridium; *o*, oögonium. At the right are a young antheridium and archegonium.

290. Characeæ. — *Nitella* and *Chara* are the genera composing the group *Characeæ*, a group of green algæ differing widely from any others. They show in a wonderful manner simplicity of cell-structure with a high degree of organization. Scarcely less wonderful are the care and precision with which botanists have worked out their life history. As a study in evolution the *Characeæ* may be considered as representing the highest development attained along the line of filamentous green algæ, which, while preserving their algal characteristics, are comparable in a remarkable degree with moss- and fern-plants and with seed-plants. Every cell in the plant has been accounted for and is understood in regard to origin, relationship, and function. With harmony of structure throughout, it has organs comparable to root, stem, and leaf in seed-plants, each with characteristic structure and

mode of growth. The stem has nodes and internodes. The stem increases by the growth of an apical cell, but growth in length depends chiefly on the elongation of each internodal cell instead of the multiplication of numerous internodal cells.

THE STUDY OF ROCKWEED[1]

291. Occurrence. — The common rockweed is abundant everywhere on rocks, between high and low tide, on the New England coast and southward.

FIG. 183. — Part of Thallus of a Rockweed (*Fucus platycarpus*), natural size. The two uppermost branchlets are fertile.

292. The Frond. — A plant of rockweed consists mostly of a growth which is somewhat leaf-like, but, in fact, stem and leaf are not separately developed, and the growth is therefore called a *thallus*. This combined stem and leaf has many flat leathery branches which are buoyed up in the water by air-bladders. Cut one of the bladders open and note its form and appearance. Note whether they occur singly or how grouped. Note the prominent midrib running throughout the middle of each branch. Examine the swollen tips of some of the branches and note their peculiarities. Sketch a portion of a frond to show the characteristics so far noted.

293. Reproduction. — Cut across through the middle of one of the swollen fruiting tips. Note the fruiting papillæ (*conceptacles*) as they appear in this section, and make a simple sketch to show their position.

Select some plants with brighter colored tips and some less bright, if any difference

[1] *Fucus vesiculosus* is the most available species. Others may be substituted.

can be detected. After making the microscopic examination which follows, note what correspondence of structure with color has been observed. Cut very thin sections through fruiting tips from different plants, keeping those from each plant separate. Be sure that some of the cuts pass through the conceptacle as near the middle as possible.

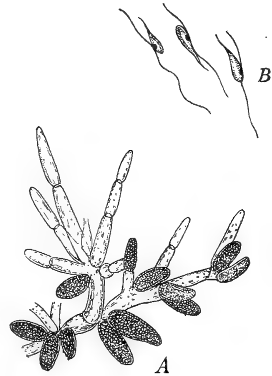


FIG. 184.—Rockweed (*Fucus*). *A*, antheridia borne on branching hairs, × 160; *B*, antherozoids from same, × 330.

Examine with a power of about sixty diameters sections from different fronds, searching for one kind containing rather large egg-shaped cells and another containing bundles of numerous smaller sac-shaped cells. With a power of 200 diameters study the details of the sections. Note the character of the cells forming the surface of the frond, those of the inner structure, and those limiting the cavity of the conceptacle. In a conceptacle cut through the middle note the form of the orifice. Examine the slender hairs or filaments (*paraphyses*) which, arising at right angles, line the walls of the conceptacle.

294. Oögonia and Antheridia. — In conceptacles containing egg-shaped cells (*oögonia*) note the form, mode of attachment (sessile or stalked), and different stages of development. At maturity the contents are divided, forming eight oöspheres; but not all can be seen at once, some being beneath the others.

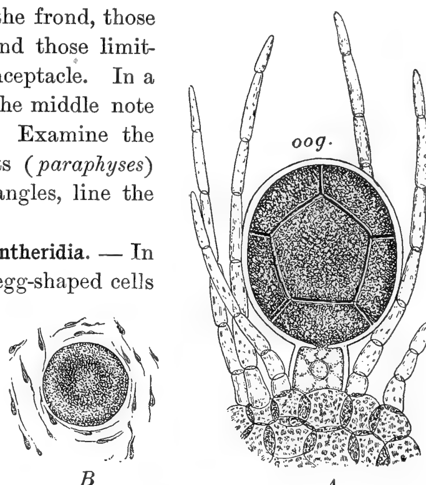


FIG. 185.—Rockweed (*Fucus*). *A*, oögonium, its contents dividing into eight oöspheres, × 160; *B*, an oösphere, escaped, surrounded by antherozoids, × 160.

In conceptacles of the other kind examine the numerous small sac-shaped cells (*antheridia*). At maturity the contents of each divide to form numerous very minute motile *antherozoids*, each with two delicate hairs or cilia. Dissect, by picking and by friction under cover-glass, a bunch of antheridia and note the branching filaments upon which they are borne.

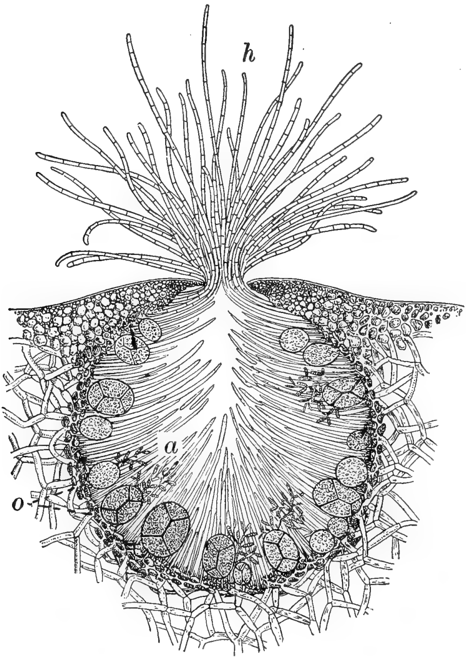


FIG. 186.—Transverse Section of Conceptacle of a Rockweed (*Fucus platycarpus*). (× about 35.)

h, hairs; *a*, antheridia; *o*, oögonia.

Make drawings to illustrate the various points of structure.

295. Number of Antherozoids required for Fertilization.—The bulk of an oösphere has been estimated equal to that of thirty thousand to sixty thousand antherozoids, but apparently an oösphere may be fertilized by only one antherozoid. Yet a large number swarm around each oösphere after both have escaped from the conceptacles, and often their movements are so active as to cause the rotation of the oösphere. The process of fertilization may be discerned in fresh material by squeezing oöspheres and antherozoids from their respective conceptacles into a drop of water on a slide. In some species, as *Fucus platycarpus* (Fig. 186), antheridia and oögonia are found in the same conceptacle.

THE STUDY OF NEMALION

296. Occurrence. — Seven or eight species of *Nemalion* are known in the world, but only one[1] is widely diffused, being found in Europe and on the New England coast from Rhode Island northward. It grows in salt water attached to exposed rocks at low-water mark. *Nemalion* represents the largest of the groups of algæ, nearly all of which live in salt water and have the characteristic color; but a few live in fresh water.

297. Color. — Fresh specimens or those properly dried for the herbarium show the color which is characteristic of the great group to which *Nemalion* belongs. Dried specimens of "Irish moss" (*Chondrus*) and many other species furnish good illustrations. There are many variations of shade and intensity.

Place a piece of a fresh or dried specimen of some species in a beaker of fresh water over night or longer and note the color of the solution and of the treated specimen. Treat another piece similarly with alcohol. A few genera related to *Nemalion* grow in fresh water. What do you infer regarding their color?

298. Form and General Character. — Examine specimens of *Nemalion* and note the size, shape, mode of branching, nature, or consistency of their substance. Examine a fragment of the plant with a power of about sixty diameters and note how the structure differs from what it appears to be to the naked eye. Do cells appear more densely packed or differently colored at any points?

299. Structure. — From a small portion of the plant cut thin longitudinal and transverse sections or pull it to pieces with needles so as to expose the inner portion. Place on a slide under a cover-glass in a drop of water. With a power of about 250 diameters or more examine the general structure of the frond, as shown by a slide prepared as above. Note the central portion (*axis*) of the frond as dissected out, consisting of long, slender, thread-like cells. Examine and draw the branching rows of cells which, radiating from the axis, form the surrounding outer structure of the frond. Note the tips of these branches and look for the fruiting organs and fruit (*spores*).

[1] *Nemalion multifidum.*

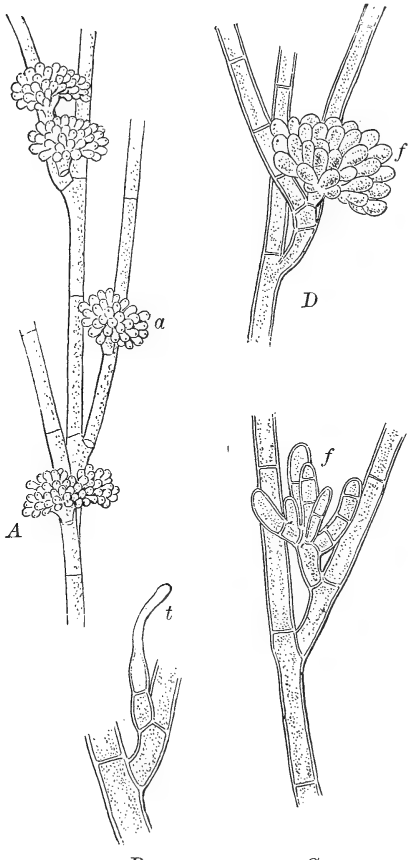


FIG. 187.—Portions of Thallus of a Red Alga (*Chantransia*). (Much magnified.)

A, filaments with antheridia, *a*; *B*, young receptive hair, or *trichogyne*, *t*; *C* and *D*, successive stages in the growth of the clustered fruit, *f*.

300. Organs for Reproduction. — The fruiting organs are to be sought on the radiating branching filaments and are usually produced in great abundance during the summer. Various stages of development may be expected at a given time. The antherozoids are small spheres without cilia, non-motile, with a thin cell-wall. Look for cells in which they are formed (*antheridia*), occurring in groups at the tips of the branches. Compare these with the vegetative cells.

301. Spore-Production. —Look for spore-producing organs in various stages. In the young stage at the time of fertilization, antherozoids, carried by currents of water, may be found adhering. Note the shape of the tip (*trichogyne*) and the base (*carpogonium*), and find whether there is any partition separating them at this stage. Draw or describe a few later stages in development, and note the arrangement of the spores at maturity. Are they naked or enclosed in any sort of envelope? Are they arranged in masses, chains, or otherwise?

302. Other Florideæ. — *Nemalion* represents one of the simplest modes of fruiting in the red algæ. In others there is great variety in structure and great complication in the mode of fruiting. Some species of *Polysiphonia* (or *Dasya*) may well be studied in comparison with *Nemalion* and in further illustration of this important group.[1] Understanding that a siphon, in algæ, is a row of cells, end to end, study the structure of a plant of *Polysiphonia* as illustrating its name. How many siphons are there? Do the main branches have any other cells covering the surface (corticating cells)?

Note the tufts of repeatedly forking, one-siphoned filaments.

303. Fruiting of Polysiphonia. — The antheridia are to be sought on the branching filaments just mentioned. Note how they differ from those of *Nemalion*. The clustered fruits or *cystocarps* will be recognized as ovoid-globose or urn-shaped bodies attached externally to the frond. Note whether the group of spores is naked or otherwise, whether the spores are produced singly or in chains; how attached; shape.

Many *Florideæ* have another kind of fruiting bodies, spores produced without fertilization, coördinate with the asexual spores of black mould (see Sect. 308). In *Florideæ* such spores are usually found in fours and are called *tetraspores*.

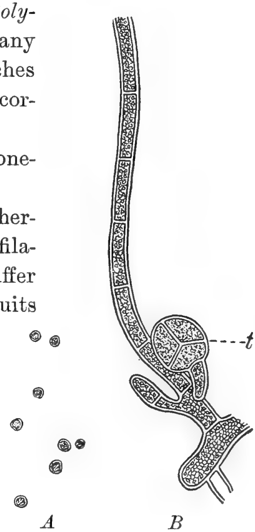


FIG. 188.

A, spores of *Nemalion* (greatly magnified); *B*, portion of thallus of a red alga, *Lejolisia*, with tetraspores, *t*.

Are tetraspores usually found on separate plants?

In *Polysiphonia* the tetraspores appear to be formed in threes (*tripartite*), the fourth being underneath the three. When found, describe their position and arrangement.

304. Algæ. — *Diatom, Oscillatoria, Pleurococcus, Spirogyra, Vaucheria, Nitella, Fucus, Nemalion,* these eight

[1] It is desirable also to exhibit fresh or pressed specimens of various genera to show their general aspect.

plants which we have just studied, are types of several families of plants which together make the great group called *Algæ*. Something of its importance in nature is indicated by these facts: The number of known species is about 12,000. In size, the individuals in various species range from a single cell of microscopic dimensions, as in *Pleurococcus*, to the giant kelp of California which reaches a length of more than 1000 feet. The form ranges from a simple spherical cell as in *Pleurococcus* to an extensive, branching cell in *Vaucheria* and its allies, specialized organs in the form of root, stem, leaf, air-bladder, and fruiting organs in *Sargassum*, which is an ally of *Fucus*.

The algæ illustrate a series of modes of propagation from simple division in *Oscillatoria* to the union of two similar masses of protoplasm to form a spore in *Spirogyra*, the direct fertilization of a germ-cell by motile antherozoids in *Vaucheria*, *Nitella*, *Fucus*, the indirect fertilization of fruiting cells by non-motile antherozoids in *Nemalion*. In allies of the latter there are more intricate variations of the same mode.

The algæ fall into five natural groups based primarily on the mode of fruiting. In most cases color is coördinate with class and may be relied upon as a superficial guide in grouping; but there are a few exceptions, *e.g.*, some fruiting like the red group are, nevertheless, green.

The nutrition of the brown and the red algæ is similar to that of the green algæ, since the brown or red color merely conceals the green of the chlorophyll which is present in all and enables them all to take in and decompose carbon dioxide.[1]

[1] See Murray's *Introduction to the Study of Seaweeds*, pp. 4–6. London, 1895.

305. Classification of Types studied.

DIATOMACEÆ. *Diatoms.*	Yellowish.
CYANOPHYCEÆ. *Oscillatoria.*	Blue-green or some similar color.
CHLOROPHYCEÆ. *Pleurococcus, Spirogyra, Vaucheria, Nitella.*	Green.
PHÆOPHYCEÆ. *Fucus.*	Olive.
FLORIDEÆ. *Nemalion. Polysiphonia.*	Red.

THE STUDY OF BLACK MOULD (RHIZOPUS NIGRICANS)

306. Occurrence. — This mould may be found in abundance on decaying fruits, such as tomatoes, apples, peaches, grapes, and cherries, or on decaying sweet potatoes or squashes. For class study it may most conveniently be obtained by putting pieces of wet bread on plates for a few days under bell-jars and leaving in a warm place until patches of the mould begin to appear.

307. Examination with the Magnifying Glass. — Study some of the larger and more mature patches and some of the smaller ones. Note:

(*a*) The slender, thread-like network with which the surface of the bread is covered. The threads are known as *hyphæ*, the entire network is called the *mycelium*.

(*b*) The delicate threads which rise at intervals from the mycelium and are terminated by small globular objects. These little spheres are spore-cases. Compare some of the spore-cases with each other and notice what change of color marks their coming to maturity.

308. Examination with the Microscope. — Sketch a portion of the untouched surface of the mould as seen (opaque) with a two-inch objective, then compare with Fig. 189.

Wet a bit of the mould, first with alcohol, then with water. Examine in water with the half-inch objective, and sketch a little of the mycelium, some of the spore-cases, and the thread-like stalks on which they are borne. Are these stalks and the mycelium filaments solid or tubular? Are they one-celled or several-celled?

Mount some of the mature spore-cases in water, examine them with the highest obtainable power, and sketch the escaping spores.

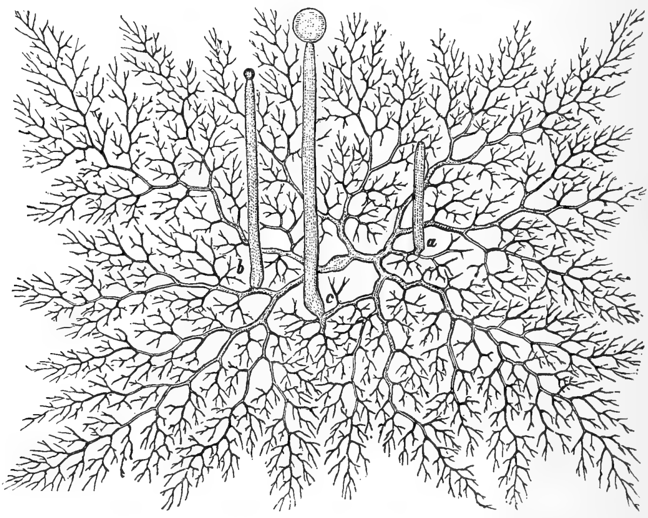


FIG. 189. — Unicellular Mycelium of a Mould (*Mucor Mucedo*), sprung from a Single Spore.

a, *b*, and *c*, branches for the production of spore-cases, showing various stages of maturity. (Considerably magnified.)

Sow some of these spores on the surface of "hay-tea," made by boiling a handful of hay in just water enough to cover it and then straining through cloth or filtering through a paper filter. After from three to six hours examine a drop from the surface of the liquid with a medium power of the microscope (half-inch objective) to see how the development of hyphæ from the spores begins. Sketch.

After about twenty-four hours examine another portion of the mould from the surface of the liquid and study the more fully developed mycelium. Sketch.

309. Zygospores. — Besides the spores just studied, *zygospores* are formed by conjugation of the hyphæ of the black moulds. It is not very easy to find these in process of formation, but the student may be able to gather from Fig. 190 the nature of the process by which they are formed, — a process which cannot fail to remind him of the conjugation of pond-scum.

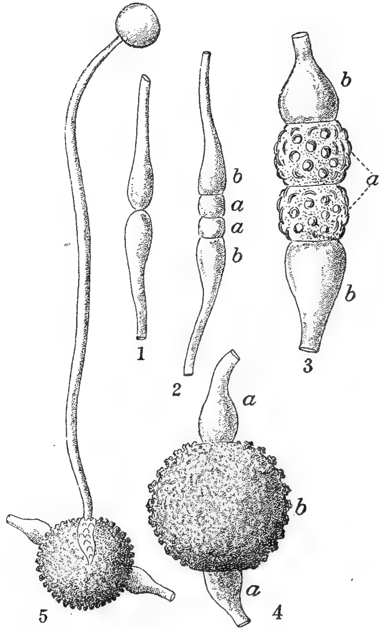


FIG. 190. — Formation of Zygospores in a Mould (*Mucor Mucedo*).

1, threads in contact previous to conjugation; 2, cutting off of the conjugating cells, *a*, from the threads, *b*; 3, a later stage of the process; 4, ripe zygospore; 5, germination of a zygospore and formation of a spore-case. (1–4 magnified 225 diameters, 5 magnified about 60 diameters.)

THE STUDY OF WHEAT RUST (PUCCINIA GRAMINIS)

310. Occurrence. — Wheat rust is common on cultivated wheat and other grains, and also on many wild and cultivated forage grasses. In fact, this or similar rusts occur on a very large number of grasses, and many species of such rusts are recognized. A rust may have one, two, or three kinds of spores, and when three occur one is known as the *cluster-cup stage* and the others as *red rust* and *black rust*, according to the usual approximate color of the spores. The rust called *Puccinia graminis* growing on wheat has its cluster-cup stage on the leaves of barberry in June. The spores from the cluster-cups are carried by the wind to the wheat, where they germinate and in a few days produce the

red rust. A little later the black spores appear, produced from the same mycelium. This growth is chiefly upon the stems and sheaths.

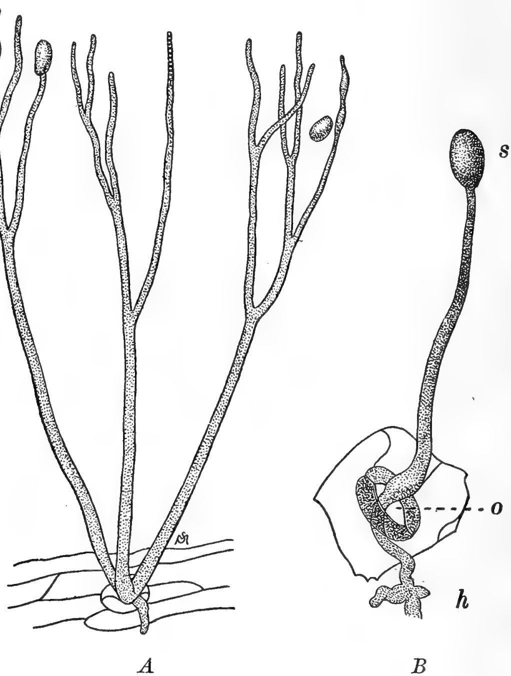


FIG. 191. — Spore-Formation in Potato-Blight (*Phytophthora infestans*).

A, a well-developed group of stalks, proceeding from a mass of mycelium inside the leaf and escaping through a stoma; *B*, a young, unbranched stalk. *h*, hyphæ of mycelium; *o*, stoma; *s*, spore. (Both figures greatly magnified, *B* more than *A*.)

311. Cluster-Cup Stage. — Note with the naked eye and with a magnifying glass the appearance of the cluster-cups upon the barberry leaf. Fresh specimens should be used, if available. Note whether the leaf is changed in form or color in any part occupied by the fungus. Note the number of cups in a cluster, the position on the leaf (which surface?), the form and size, especially the height.

Are they straight or curved? Describe the margin of the cup, the color without, and the color of the contents.

With a power of 200 diameters or more examine some of the cells composing the cup and note the form, color, and nature of the surface. Draw. With the point of a needle or knife pick out a bit of the contents of the cup and examine as above. Note the characters as before and compare in detail with the cells of the cup. The cells within the cup are the spores. Can you tell how they are attached?

A thin section through the cup will show the mode of attachment and the relation of the spores to the cup.

312. Examination of Red and Black Rust. — Under the magnifying glass examine the eruptions of spores (*sori*) on the wheat plant, some of red spores and some of black spores. The red spores are faded in dried specimens. Note the approximate size and shape and any other peculiarities. Prepare slides of each kind of spores and see if both can be found in one sorus. The spores may be taken from the host-plant on the point of a knife by picking rather deeply down into the sorus. Place the small quantity of spores so

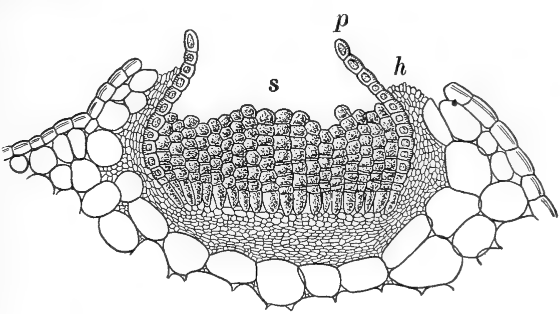


FIG. 192.—A Cluster-Cup of Anemone Rust (*Puccinia fusca*). (× 120.) *s*, chains of spores; *p*, the covering or peridium of the cup; *h*, hyphæ.

obtained in a drop of water on a slide, spread with dissecting needles and cover. Examine under a power of 200 or more diameters.

The red spores (*uredospores*) have each a stalk from which they easily fall. They may be seen attached to their stalks if properly

prepared cross-sections through the sorus are available, especially if the material is fresh. Examine the spores and note the shape, color, and surface. If the spores are shrunken, a drop of potash solution will restore the natural plumpness. Draw. Spore-measurements are important in determining species. The *uredospores* of *Puccinia graminis* may be distinguished from those of other species common on grasses by the greater proportionate length.

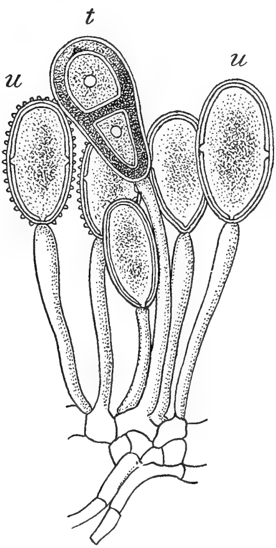


FIG. 193.—A Group of Spores of Wheat Rust (*Puccinia graminis*). (× about 440.) *u*, *u*, uredospores; *t*, a teleutospore.

The structure of the black spores (*teleutospores*) can be made out without difficulty. Some should be found attached at the base. Note the parts and the differences in color in different portions. Make careful drawings to show shape and structure of both kinds of spores.

Boil a portion of a rust-injured plant in potash solution, pick it to pieces on a slide under the magnifier or dissecting microscope, use a cover-glass and examine the preparation for mycelium, using a high power.

313. Cultivation on a Host-Plant. — If practicable, find some wheat or grass which has remained over winter with the black rust upon it. Tie a bunch of this to a barberry bush while the leaves are young or unexpanded. When the time arrives for the appearance of the cluster-cups, note whether they are any more abundant on this bush than on others. Are you sure that the rust you have is the one to which the barberry cluster-cups belong?

THE STUDY OF MICROSPHÆRA

314. Occurrence. — Species of *Microsphæra* and allied forms occur in late summer and fall on leaves of various herbaceous and woody plants. The growth is confined to the surfaces of the leaf (upper, lower, or both). Among the most available species are those which grow upon lilac, oak, grape, cherry, willow, and wild plants of the sunflower family. Some species are known to occur on only one host-plant, others occur on several or a large number, and the host-plants may belong to one or more than one family.

Besides *Microsphæra* there are about five other genera, any of which may be substituted or studied comparatively. They are distinguished by the form of the appendages, together with the number of spore-sacs (*asci*) in each sac-receptacle or *perithecium.*

The species of fungi which *Microsphæra* represents are called *powdery mildews.*

With naked eye and magnifying glass examine the surface of a leaf bearing powdery mildew. Note which surface and what portion of the surface is occupied by the fungus, whether the occupied area is restricted or not, the color, and any other characters.

315. Examination with the Microscope. — Place a small drop of water on the leaf where the fungus occurs, if possible where dark-colored specks occur among the mycelium. Pick from the leaf a portion of the fungus loosened by the water and place with a drop of water on a slide. Place a cover-glass over it. Examine under a power of about fifty diameters. The dark-colored specks will be seen as somewhat spherical bodies (*perithecia*). Note their structure and color and their appendages. Have the perithecia any regular way of opening? Note the length of the appendages as compared with the diameter of the perithecia; also note the form of the tips and of the base, the color and any variation of color in different parts of the appendages. Keep the left hand on the focusing screw, and with the needle in the right hand press with gentle but varying stress upon the cover-glass to rupture the perithecia. Even with great care broken cover-glasses may result, but this pressure should force out the contents of the perithecia. Another method is to remove the slide from the microscope and, with a pencil rubber

applied to the cover-glass, rupture the perithecia by gentle grinding between the cover and slide. Note the number and form of the spore-sacs (*asci*) expelled from each of several perithecia. Examine under a power of about 200 diameters and count the number of spores in the asci. Gentle pressure may make them more distinctly visible. Make drawings to illustrate the structural characters observed.

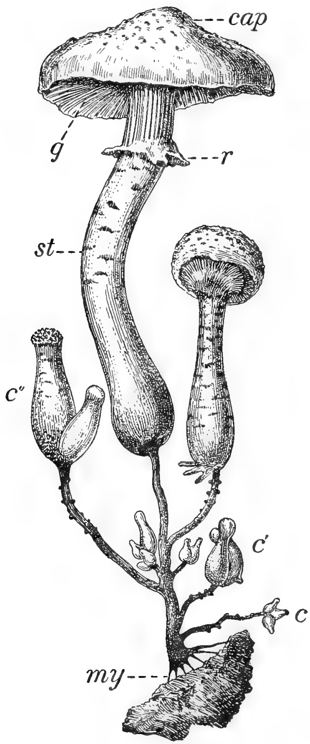


FIG. 194. — A Mushroom (*Agaricus melleus*).

my, mycelium; *c*, *c′*, *c″*, young "buttons"; *st*, stipe or stalk; *r*, ring; *g*, gills.

THE STUDY OF AGARICUS

316. Occurrence. — The common mushroom, *Agaricus campestris*, grows in open fields and pastures in the United States and Europe. It is the mushroom most extensively cultivated for market, and if not found in the field it may be raised from "spawn" (*mycelium*), put up in the shape of bricks, and sold by seedsmen in the large cities. Those who make a specialty of selling it furnish directions for culture free. A moderately warm cellar or basement makes an excellent winter garden for mushrooms.

317. Structure of Mycelium. — Examine some of the spawn, or mycelium, with the magnifying glass and the low power of the microscope, and with a power of 200 diameters or more examine the individual hyphæ which compose it. Are the hyphæ united in cord-like strands or otherwise, or are they entirely separate? Look for cross-partitions in the hyphæ. Is there any peculiar structure to be found at these places? Are the cross-partitions near together or widely separated?

318. The Spore-Plant. — Search for indications of fruiting, and note the appearance of the "button mushrooms" in all available stages. Draw. See if at any stage up to maturity an outer envelope of tissue (*volva*) can be found enclosing the entire fruiting body. If such be present, what becomes of it at maturity? If material is available, compare the species of *Amanita* (poisonous) in regard to this.

Examine specimens in which the cap is expanding and see if there is another tissue forming a *veil* covering the under surface of the cap. If such be present, how is it attached and what becomes of it?

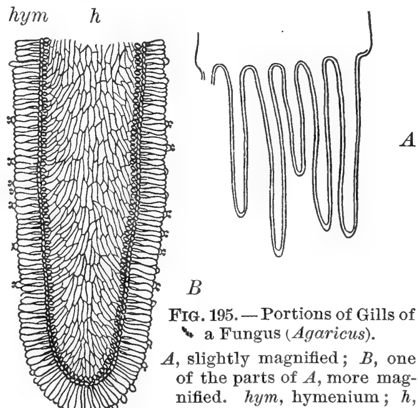


FIG. 195. — Portions of Gills of a Fungus (*Agaricus*). *A*, slightly magnified; *B*, one of the parts of *A*, more magnified. *hym*, hymenium; *h*, central layer.

Take a fresh, well-expanded mushroom or toadstool. Remove the stalk, or *stipe*, close under the cap, or *pileus*, and lay the latter, gills down, on a piece of paper. Let it remain undisturbed for a few hours, or over night, so that the spores may fall upon the paper. Note carefully their color, also the form in which they are arranged on the paper. What determines this form? Examine some of the spores under the highest available power of the microscope. Measure and draw.

Describe the stipe. Is it a hollow tube or solid? Does it taper? Note length, diameter, color.

Describe the cap, or pileus, in regard to diameter, thickness, nature and color of the upper surface, also color below.

Examine the plates, or *gills*, which compose the under portion of the pileus. Cut a complete pileus and stipe, through the center, and draw an outline to show the shape, noting particularly how the gills are attached. What is the color of the gills?

319. Origin of Spores. — Make a cross-section of one of the gills, and with a magnifying power of about 200 diameters examine the

fruiting cells (*basidia*) which project at right angles to the gill and bear the spores. At how many points (*sterigmata*) on each basidium are spores attached? Draw a basidium, preferably one from which the spores have not yet fallen.

THE STUDY OF YEAST (SACCHAROMYCES CEREVISIÆ)

320. Growth of Yeast in Dilute Syrup. — Mix about an eighth of a cake of compressed yeast with about a teaspoonful of water and stir until a smooth, thin mixture is formed. Add this to about half a pint of water in which a tablespoonful of molasses has been dissolved. Place this mixture in a wide-mouthed bottle which holds one or one and a half pints, stopper *very loosely*[1] and set aside for from twelve to twenty-four hours in a place in which the temperature will be from 70 to 90 degrees. Watch the liquid meantime and note:

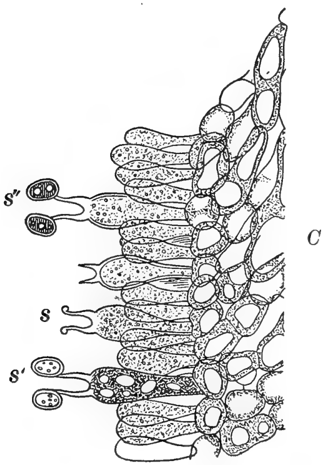


FIG. 196. — Part of the Preceding Figure. (× about 300.)

C, layer of cells immediately under the hymenium; *s*, *s'*, *s''*, three successive stages in growth of spores.

(*a*) The rise of bubbles of gas in the liquid.

(*b*) The increasing muddiness of the liquid, a considerable sediment usually collecting at the end of the time mentioned.

(*c*) The effect of cooling off the contents of the bottle by immersing it in broken ice if convenient, or, if this is not practicable, by standing it for half an hour in a pail of the coldest water obtainable, or leaving it for an hour in a refrigerator, afterwards warming the liquid again.

(*d*) The effect of shutting out light from the contents of the bottle by covering it with a tight box or large tin can.

[1] If the cork is crowded into the neck with any considerable force, pressure of gas and an explosion may result.

(*e*) The result of filling a test-tube or a very small bottle with some of the syrup-and-yeast mixture, from which gas-bubbles are freely rising, and immersing the small bottle up to the top of the neck for fifteen minutes in boiling water. Allow this bottle to stand in a warm place for some hours after the exposure to hot water. What has happened to the yeast-plants?

(*f*) The behavior of a lighted match lowered into the air space above the liquid in the large bottle, after the latter has been standing undisturbed in a warm place for an hour or more.

(*g*) The smell of the liquid and its taste.

321. Microscopical Examination of the Sediment.[1] — Using a very slender glass tube as a pipette, take up a drop or two of the liquid and the upper layer of the sediment and place on a glass slide, cover with a very thin cover-glass and examine with the highest power that the microscope affords.

Note:

(*a*) The general shape of the cells.

(*b*) Their granular contents.

(*c*) The clear spot, or vacuole, seen in many of the cells.

Sketch some of the groups and compare the sketches with Fig. 197.

Run in a little iodine solution under one edge of the cover-glass, at the same time touching a bit of blotting paper to the opposite edge, and notice the color of the stained cells. Do they contain starch?

Place some vigorously growing yeast on a slide under a cover-glass and run in a little eosin solution or magenta solution. Note the proportion of cells which stain at first and the time required for others to stain. Repeat with yeast which has been placed in a slender test-tube and held for two or three minutes in a cup of boiling water.

With a very small cover-glass, not more than three-eighths of an inch in diameter, it may be found possible by laying a few bits of blotting paper or cardboard on the cover-glass and pressing it against the slide to burst some of the stained cells and thus show their thin, colorless *cell-walls* and their semi-fluid contents, *protoplasm*, nearly colorless in its natural condition but now stained by the iodine.

[1] See Huxley and Martin's *Biology*, under *Torula*.

EXPERIMENT XXXIX

Can Yeast grow in Pure Water or in Pure Syrup? — Put a bit of compressed yeast of about the size of a grain of wheat in about four fluid ounces of distilled water, and another bit of about the same size in four fluid ounces of 10 per cent solution of rock candy in distilled water; place both preparations in a warm place, allow to remain for twenty-four hours, and examine for evidence of the growth of the yeast added to each.

322. Size, Form, and Structure of the Yeast-Cell. — The student has discovered by his own observations with the microscope that the yeast-cell is a very minute object, — much smaller than most of the vegetable cells which he has hitherto examined. The average diameter of a yeast-cell is about $\frac{1}{3000}$ of an inch, but they vary greatly both ways from the average size.

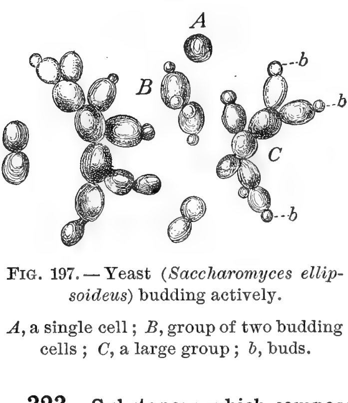


FIG. 197. — Yeast (*Saccharomyces ellipsoideus*) budding actively.

A, a single cell; *B*, group of two budding cells; *C*, a large group; *b*, buds.

The general form of most of the cells of ordinary yeast is somewhat egg-shaped. The structure is extremely simple, consisting of a thin cell-wall, which is wholly destitute of markings, and a more or less granular semi-fluid protoplasm, sometimes containing a portion of clearer liquid, the *vacuole*, well shown in the larger cells of Fig. 197.[1]

323. Substances which compose the Yeast-Cell. — The cell-wall is composed mostly of *cellulose;* the protoplasm consists largely of water, together with considerable portions of a proteid substance,[2]

[1] This is not the ordinary commercial yeast.

[2] It may be found troublesome to apply tests to the yeast-cell on the slide, under the cover-glass. Testing a yeast cake is not of much value, unless it may be assumed that compressed yeast contains little foreign matter and consists mostly of yeast-cells. Still the test is worth making. Millon's reagent does not work well, but the red or maroon color which constitutes a good test for proteids is readily obtained by mixing a teaspoonful of granulated sugar with enough strong sulphuric acid to barely moisten the sugar throughout, and then, as quickly as possible, mixing a bit of yeast cake with the acid and

some fat, and very minute portions of *sulphur*, *phosphorus*, *potash*, *magnesia*, and *lime*. It is destitute of chlorophyll, as would be inferred from its lack of green color, and contains no starch.

324. Food of the Yeast-Cell; Fermentation. — The diluted molasses in which the yeast was grown in Exp. XXXIX contained all the mineral substances mentioned in Sect. 323, together with sugar, proteid materials, and water. The addition of a little nitrate of ammonium would probably have aided the growth of the yeast in this experiment, by supplying more abundantly the elements out of which the yeast constructs its proteid cell-contents. A great deal of sugar disappears during the growth of the yeast.[1] Most of the sugar destroyed is changed into carbon dioxide (which the student saw rising through the liquid in bubbles) and alcohol, which can be separated from the liquid by simple means. The process of breaking up weak syrup into carbon dioxide and alcohol by aid of yeast is one kind of *fermentation;* it is of great practical importance in bread-making and in the manufacture of alcohol. Since grape juice, sweet cider, molasses and water, and similar liquids, when merely exposed to the air soon begin to ferment and are then found to contain growing yeast, it is concluded that dried yeast-cells, in the form of dust, must be everywhere present in ordinary air.

325. Yeast a Plant; a Saprophyte. — The yeast-cell is known to be a plant, and not an animal, from the fact of its producing a coating of cellulose around its protoplasmic contents and from the fact that it can produce proteids out of substances from which animals could not produce them.[2]

On the other hand, yeast cannot live wholly on carbon dioxide, nitrates, water, and other mineral substances, as ordinary green plants can. It gives off no oxygen, but only carbonic acid gas, and is therefore to be classed with the *saprophytes*, like the Indian pipe, among flowering plants (Sect. 180).

sugar. A comparative experiment may be made at the same time with some other familiar proteid substance, *e.g.*, wheat-germ meal.

[1] The sugar contained in molasses is partly cane sugar and partly grape sugar. Only the latter is detected by the addition of Fehling's solution. Both kinds are destroyed during the process of fermentation.

[2] For example, tartrate of ammonia.

326. Multiplication of Yeast. — It is worth while to notice the fact that yeast is one of the few cryptogams which have for ages been largely cultivated for economic purposes. Very recently yeast producing has become a definite art, and the cakes of compressed yeast so commonly sold afford only one instance of the success that has been attained in this process. While yeast-cells are under favorable conditions for growth, they multiply with very great rapidity. Little protrusions are formed at some portion of the cell-wall, as the thumb of a mitten might be formed by a gradual outgrowth from the main portion. Soon a partition of cellulose is constructed, which shuts off the newly formed outgrowth, making it into a separate cell, and this in turn may give rise to others, while meantime the original cell may have thrown out other off-shoots. The whole process is called *reproduction by budding*. It is often possible to trace at a glance the history of a group of cells, the oldest and largest cell being somewhere near the middle of the group and the youngest and smallest members being situated around the outside. Less frequently the mode of reproduction is by means of *spores*, new cells (usually four in number), formed inside one of the older cells (*ascus*). At length the old cell-wall bursts, and the spores are set free, to begin an independent existence of their own.

In examining the yeast-cell the student has been making the acquaintance of plant life reduced almost to its lowest terms. The very simplest plants consist, like the slime moulds, of a speck of jelly-like protoplasm. Yeast is more complex, from the fact that its protoplasm is surrounded by an envelope of cellulose, the cell-wall.

THE STUDY OF PHYSCIA

327. Occurrence. — *Physcia* is one of the commonest lichens. It grows attached to the bark of various trees.

328. The Thallus. — *Physcia* consists chiefly of an irregularly expanded growth somewhat leaf-like in texture. It is best to be wet for study. Is it separable from the bark to which it is attached or is it combined with it (incrusted)? Describe the general outline of the margin, the general color, and any special variations of color above, also below. How is the thallus attached to the bark?

329. The Fruit. — Look for small lance-shaped disks seated upon the thallus. Note the approximate sizes and color within and without. These disks are called *apothecia.* Note the very minute black specks (*spermogones*) which are scattered in the surface of the thallus. Pick one from the thallus, with as little of the thallus as possible, and examine under high power. It may be macerated in a drop of potash solution and crushed under the cover-glass. If the contents are not easily defined, they may then be made more opaque by a drop of acetic acid or a stain. The minute colorless bodies contained in the spermogones are called *spermatia.* Their office in *Physcia* is obscure, but in a few lichens they are thought to unite with a trichogyne cell, as in the red algæ.[1] Note the minute, powdery masses (*soredia*) on the surface of the thallus. Macerate if necessary under the cover-glass and examine under a high power. Compare with the structure of the thallus as seen in cross-section. (See next paragraph.) These soredia easily become detached and develop into new plants.

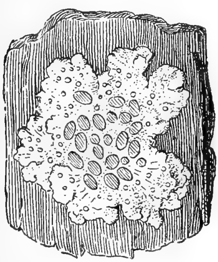


FIG. 198. — A Lichen (*Xanthoria*). (Natural size.)

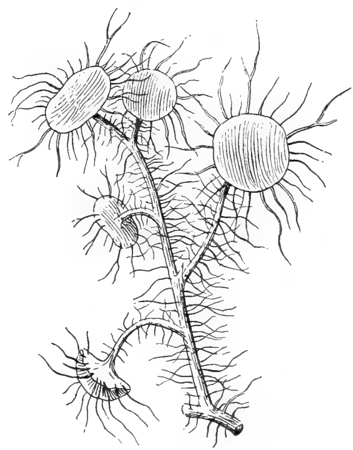


FIG. 199. — A Lichen (*Usnea*). (Natural size.)

Prepare for sectioning by imbedding a small portion of the thallus with an apothecium in a piece of pith or by any suitable device for sectioning, and cut thin sections of thallus and fruit.

[1] This, however, is doubtful. See Strasburger, Noll, Schenk, and Schimper's *Text-Book of Botany*, p. 380.

330. Examination of the Thallus. — The thallus of *Physcia* as seen in cross-section will be found to consist of four layers, the upper cortical, gonidial, medullary, and the lower cortical. The cortical layers will be seen to serve for protection, answering the purpose of an epidermis or bark. The cells which compose them make what is called a *false parenchyma*, — resembling parenchyma in form but as to origin being transformed fungal hyphæ. Note the form of the hyphæ composing the medullary layer. Are there any cross-partitions? Do any cells appear circular, and if so, what is the explanation? The upper portion of the cortical layer, having green cells intermixed, constitutes the gonidial layer. Why should the green cells be at the upper part of the medullary layer? Can you detect any connection between the green cells and the hyphæ? Do these green cells resemble any cells previously studied?

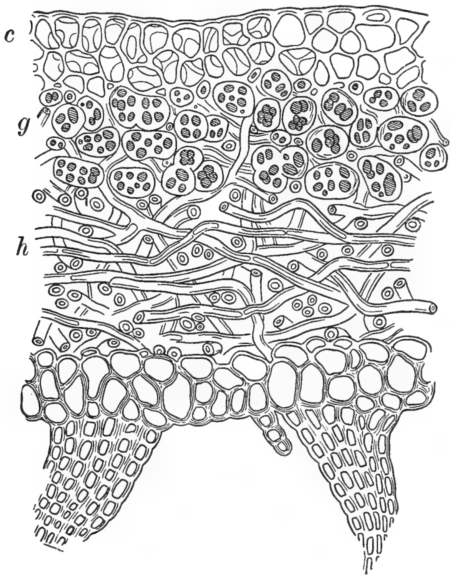


FIG. 200. — Transverse Section through Thallus of a Lichen (*Sticta fuliginosa*). (× 500.)
c, cortical or epidermal layer ; *g*, gonidia ; *h*, hyphæ.

Make a diagram to show the structure of the thallus.

What arrangement of layers would you expect to find in a lichen thallus, upright or suspended? Compare the arrangement in the fruit-body (*apothecium*), describe, and sketch. How does the layer of cells beneath the spore-sacs resemble the cortical layer? All but these two layers may be considered as part of the thallus. To make out the details of the fruit, the section must be very thin.

Examine the spore-sacs (*asci*) and look for spores in different stages of formation. How many spores are found in each ascus? What other bodies occur among the asci? Draw these, also asci and spores.

331. Lichens. — Lichens were formerly supposed to be a distinct class of plants, and it is only about thirty years since their real nature began to be understood. A lichen is now known to be a combination of two plants. The green cells, called the *gonidia*, belong to some species of alga, and the remainder, the larger portion of the growth, is a fungus parasitic upon that alga. The groups of lichens correspond in structure to certain groups of fungi, but the genera are sufficiently distinct so that lichens are best considered by themselves for purposes of study and classification.

The relation of the fungus and its algal host is not that of destructive parasitism, but rather a mutual relation (*symbiosis*) in which both fungus and alga may have a vigorous growth. The relationship has been investigated in various ways, and it has been found that, while the alga may grow independent of the fungus, the germinating fungus spores can grow only to a limited extent if deprived of the algal host; but if supplied naturally or artificially with the proper alga they make a normal growth.

The same alga may serve as gonidia to a number of lichens, often of very different form, and while the number of lichens reaches into the thousands, the number of algæ known to serve as gonidia is quite small.

Lichens are widely distributed in all zones but flourish particularly in northern regions where other vegetation is scanty. Some were formerly important as sources of

dyes. "Iceland moss" is a lichen used for food, and a finely branching form, growing in extensive mats on the soil, serves as food for the reindeer and is known as "reindeer moss."

Most lichens grow on the bark of trees, on rocks, or soil where they have little moisture except during rainfall, but some grow where they are constantly wet. Some of the latter are gelatinous. Most of the conspicuous lichens are foliaceous or else have a thallus composed of branching, cylindrical, thread-like portions. But many species, often less conspicuous, are crustaceous, growing as if they formed part of the bark or rock to which they are attached.

332. Fungi. — The yeasts, moulds, rusts, mildews, and mushrooms represent an immense group of plants of which about forty-five thousand species are now known in the world. They range from the very simple to quite complex forms, growing as saprophytes or parasites under a great variety of conditions. Their structure and life history are so varied as to constitute a long series of divisions and subdivisions.[1] Chlorophyll is absent from fungi, and they are destitute of starch, but produce a kind of cellulose which appears to differ chemically from that of other plants. Unable to build up their tissues from carbonic acid gas, water, and other mineral matters, they are to be classed, with animals, as consumers rather than as producers, acting on the whole to diminish rather than to increase the total amount of organic material on the earth.

[1] See Strasburger, Noll, Schenk, and Schimper's *Text-Book of Botany*, pp. 340–381 incl., also Potter and Warming's *Systematic Botany*, p. 1, and Engler's *Syllabus der Pflanzenfamilien*, Berlin, 1898, pp. 25–47.

333. Occurrence and Mode of Life of Fungi. — Among the most important cryptogamous plants are those which, like the bacteria of consumption, of diphtheria, of typhoid fever, or of cholera, produce disease in man or in the lower animals. The subclass which includes these plants is known by the name *Bacteria*. Bacteria are now classed by some as a separate group, lower than fungi. Some of the most notable characteristics of these plants are their extreme minuteness and their extraordinary power of multiplication. Many bacteria are on the whole highly useful to man, as is the case with those which produce decay in the tissues of dead plants or animals, since these substances would, if it were not for the destructive action of the bacteria of putrefaction and fermentation, remain indefinitely after death to cumber the earth and lock up proteid and other food needed by new organisms.

The mushrooms and their allies include about one-fourth of the fungi. Some, such as the "dry-rot" fungus, mistakenly so called, cause great destruction to living and dead tree trunks and timber in economic use. The common mushroom, *Agaricus campestris*, is the most important edible species. Probably five hundred kinds can be eaten, but only a few are good food, and even these contain but little nutriment. Some species are dangerous, and a few are deadly poisons. The puffballs are a small group allied to the mushrooms. Most of them are edible and of good quality.

The mildews (*Microsphœra*, etc.) and the "black-knot" of the plum trees are of a group which likewise includes about one-fourth of the fungi. A considerable number are parasites, injurious to vegetation, while thousands of others grow on dead leaves, twigs, etc.

The "rust" of wheat and the "smut" of corn represent groups numbering only a few hundreds of species, which are very important because they are all parasites on living plants, many on our most important economic plants.

Fig. 191, representing another small group of destructive parasites, shows clearly how a parasitic fungus grows from a spore which has found lodgment in the tissues of a leaf and pushes out stalks through the stomata to distribute its spores.

CHAPTER XXI

TYPES OF CRYPTOGAMS; BRYOPHYTES

334. The Group Bryophytes. — Under this head are classed the liverworts and the mosses. Both of these classes consist of plants a good deal more highly organized than the thallophytes. Bryophytes have no true roots, but they have organs which perform the work of roots. Some of them have leaves (Fig. 206), while others have none (Fig. 201). Fibro-vascular bundles are wanting. The physiological division of labor is carried pretty far among all the bryophytes. They have special apparatus for absorbing water and sometimes for conducting it through the stem; stomata are often present and sometimes highly developed. There are chlorophyll bodies, often arranged in cells extremely well situated for acting

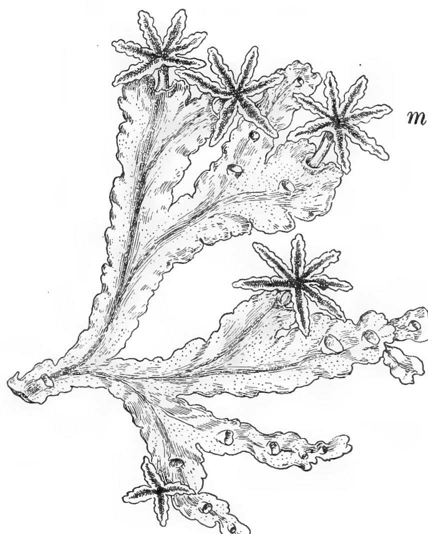


FIG. 201. — Part of Male Thallus of a Liverwort (*Marchantia disjuncta*). (Enlarged.) *mr*, male receptacle.

on the carbon dioxide gas which the plant absorbs, that is, arranged about rather large air chambers.

Reproduction is of two kinds, sexual and asexual, and the organs by which it is carried on are complicated and highly organized. An *alternation of generations* occurs, that is, the life history of any species embraces two forms: a *sexual generation*, which produces two kinds of cells that by their union give rise to a new plant; the *asexual generation*, which multiplies freely by means of special cells known as *spores*.

FIG. 202. — Part of Female Thallus of *M. disjuncta*. (Enlarged.)
fr, female receptacle; *c*, cups with gemmæ.

THE STUDY OF MARCHANTIA

335. Occurrence. — *Marchantia* grows on soil or rocks in damp shaded places and is widely distributed.

336. The Thallus. — In general form the thallus bears some resemblance to that of some of the lichens, as *Parmelia*, but is plainly different in color, mode of branching, and internal structure under the microscope. Under the microscope (see below) the individual cells may be compared with those of the medullary layer in *Physcia*.

Note the color and general shape of the thallus and study carefully the mode of branching. The origin of the growing cells is at the tip, but cells so originating afterward multiply more rapidly, so that the tip comes to be in a notch.

Viewing the thallus as an opaque object, note the diamond-shaped network on the upper surface and the dot-like circle in the middle of each diamond.

Examine the under surface for (1) rhizoids and (2) scales.

337. Internal Structure. — Cut thin cross-sections of the thallus in the same way as for *Physcia*, making some pass through the circular dots mentioned above. Examine under a high power and note the different kinds and layers of cells composing the thallus. Note the character of the cells forming the upper and lower surfaces. Describe the cells which are next above those of the lower epidermis, their shape, color of contents, approximate number of horizontal rows. Have they any evident intercellular spaces? Find cells connecting these with the upper epidermis and constituting the network of lines seen on the surface of the thallus. Note the air cavity bounded by these lines and the loose cells which occupy it in part. What is the color of their contents? How are they attached, and how arranged? Can you discover any opening through the epidermis? If so, describe it.

FIG. 203. — Section through Antheridial Receptacle of *Marchantia*. (Magnified.)

a, antheridium.

Make drawings to illustrate the details of structure observed.

338. Gemmæ. — Look for a thallus bearing little green cups formed of its own substance. Describe the contents of the cup. The bodies are called *gemmæ*. They originate by vegetative growth alone and when detached may grow into new plants.

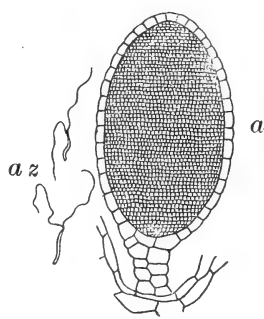


FIG. 204. — Sectional View of an Antheridium of *Marchantia*.

a, antheridium; *az*, antherozoids, × 700.

339. Fruiting Organs. — Look for thalli bearing stalks with umbrella-like expansions. The umbrellas are of two kinds, one disk-like with crenate points (how many?) and the other has rays (how many?) elongated and curving downward. Is there any difference in the height of the two kinds?

Do both occur on the same thallus? On what part of the thallus do they occur, and do they differ in this respect?

340. Antheridia. — The antheridia are formed as outgrowths from the upper surface of the crenate receptacle, but by further growth of the receptacle they become imbedded. They should be examined under a high power and sketched in outline. The antheridium produces numerous motile antherozoids, each with two cilia.

341. Archegonia and Sporophytes. — The receptacle with recurved rays bears the archegonia. Note whether they occur above or below and in what relation to the rays. How are the archegonia protected? Note the cells which surround the central canal and form the elongated neck of the archegonium. Does the archegonium open upward or downward? At the base look for the germ-cell.

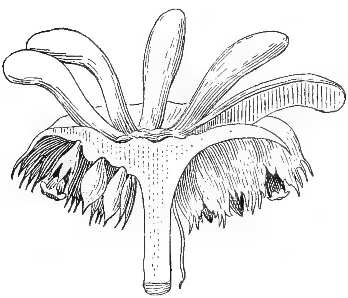


FIG. 205. — Sectional View of Female Receptacle of *Marchantia*. (× 5.)

The antherozoids enter the central canal and penetrating to the egg-cell fertilize it, after which it begins to divide and grows into a sporophyte. In the older specimens, therefore, the sporophytes will be found more or less developed. The archegonium remains upon the tip of the sporophytes. The mature sporophyte contains the spores and also peculiar elongated tapering threads with spiral thickenings. These are called *elaters*.

342. Hepaticæ. — *Marchantia* represents only a small division of the *Hepaticæ*, and is not typical of the larger number of species. In spite of this it is chosen for study, because it is widely distributed and more available for study than most others. In most species the fruit lasts but a little while and good material is hard to obtain. In Marchantia the fruiting organs are abundant, more gradual in their development, and more persistent. Marchantia and

its allies consist chiefly of the thallus in the vegetative condition, while the greater number of Hepaticæ have a stem and leaves. Thus they approach closely to the mosses. But mosses usually have leaves on all sides of the stem, while the leaves of Hepaticæ are two-ranked, spreading laterally, with sometimes a third row of leaves or scales underneath. The leaves of mosses usually have more than one layer of cells in some part, but the leaves of the leafy Hepaticæ have but one layer of cells throughout. The forms of the leaves are often very curious and interesting. The sporophyte of most mosses consists of a capsule with a lid, while in the leafy Hepaticæ the capsule usually opens by splitting longitudinally into two to four valves.

Different species of Hepaticæ grow on damp soil, rocks, and the bark of trees. Many are capable of enduring drought and reviving with moisture.

THE STUDY OF PIGEON-WHEAT MOSS (*POLYTRICHUM COMMUNE*)

343. Occurrence. — This moss is widely distributed over the surface of the earth, and some of its relatives are among the best known mosses of the northern United States. Here it grows commonly in dry pastures or on hillsides, not usually in densely shaded situations.

344. Form, Size, and General Characters. — Study several specimens which have been pulled up with root-hairs. Note the size, general form, color, and texture of all the parts of the plants examined. Some of them probably bear *spore-capsules* or *sporophytes* like those shown in Fig. 206, while others are without them. Sketch one plant of each kind, about natural size.

What difference is noticeable between the appearance of the leaves in those plants which have spore-capsules and those which have none? Why is this?

In some specimens the stem may be found, at a height of an inch or more above the roots, to bear a conical, basket-shaped enlargement,

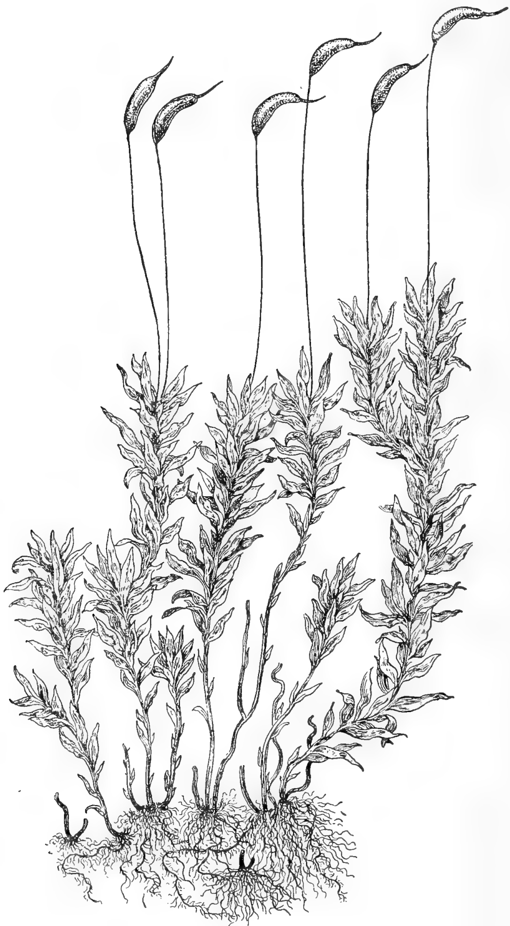


FIG. 206. — A Moss, *Catharinea*.

The sporophytes of this moss are usually rather more slender than as here represented.

out of the center of which a younger portion of the stem seems to proceed; and this younger portion may in turn end in a similar enlargement, from which a still younger part proceeds.

Note the difference in general appearance between the leaves of those plants which have just been removed from the moist collecting-box and those which have been lying for half an hour on the table. Study the leaves in both cases with the magnifying glass in order to find out what has happened to them. Of what use to the plant is this change? Put some of the partially dried leaves in water, in a

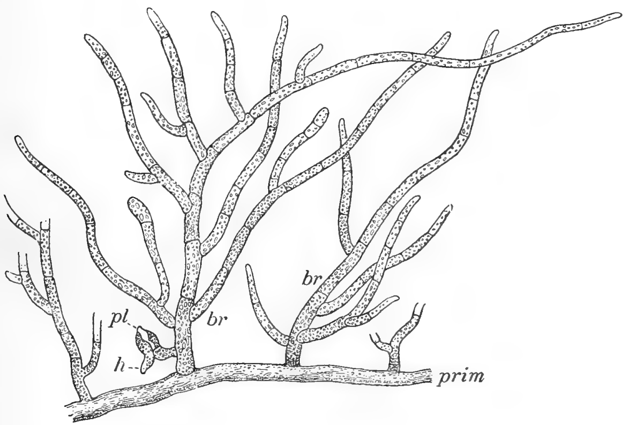


FIG. 207. — Protonema of a Moss.

prim, primary shoot; *h*, a young root-hair; *pl*, young moss-plant; *br*, branches of primary shoot.

cell on a microscope slide, cover, place under the lowest power of the microscope, and examine at intervals of ten or fifteen minutes. Finally sketch a single leaf.

345. Minute Structure of the Leaf and Stem. — The cellular structure of the pigeon-wheat moss is not nearly as simple and convenient for microscopical study as is that of the smaller mosses, many of which have leaves composed, over a large part of their surfaces, of but a single layer of cells, as shown in Fig. 209. If any detailed study of the structure of a moss is to be made, it will, therefore, be better for the student to provide himself with specimens of almost

any of the smaller genera,[1] and work out what he can in regard to their minute anatomy.

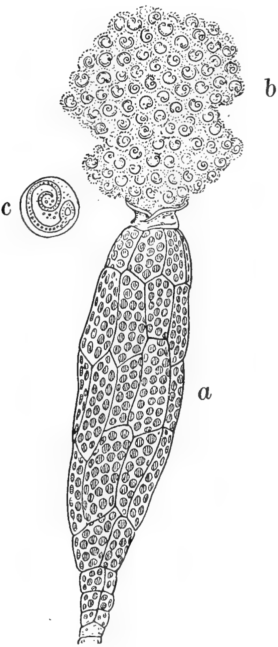


FIG. 208. — The Antheridium of a Moss (*Funaria*) and its Contents.

a, antheridium; *b*, escaping antherozoids, × 350; *c*, a single antherozoid of another moss, × 800.

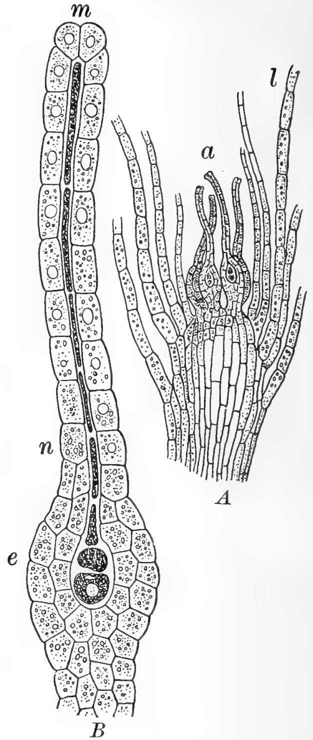


FIG. 209. — Portions of Fertile Plant of a Moss (*Funaria*).

A, longitudinal section of summit of plant, × 100; *a*, archegonia; *l*, leaves; *B*, an archegonium, × 550; *e*, enlarged ventral portion with central cell; *n*, neck; *m*, mouth.

346. Sporophytes. — That part of the reproductive apparatus of a common moss which is most apparent at a glance is the *sporophyte* or *spore-capsule* (Fig. 206). This is covered, until it reaches maturity, with a hood which is easily detached. Remove the hood from one

[1] As *Mnium* or *Bryum*.

of the capsules, examine with a magnifying glass, and sketch it. Note the character of the material of which its outer layer is composed.

Sketch the uncovered capsule as seen through the magnifying glass, noting the little knob at its base and the circular lid.

Pry off this lid, remove some of the mass of spores from the interior of the capsule, observe their color as seen in bulk through the magnifying glass, then mount in water, examine with the highest obtainable power of the microscope, and sketch them. These spores, if sown on moist earth, will each develop into a slender, branched organism, consisting, like pond-scum, of single rows of cells (Fig. 207) called the *protonema*.

347. Other Reproductive Apparatus. — The student cannot, without spending a good deal of time and making himself expert in the examination of mosses, trace out for himself the whole story of the reproduction of any moss. It is sufficient here to give an outline of the process. The protonema develops buds, one of which is shown in Fig. 207, and the bud grows into an ordinary moss plant. This plant, in the case of the pigeon-wheat moss, bears organs of a somewhat flower-like nature, which contain either *antheridia* (Fig. 208), organs which produce fertilizing cells called *antherozoids*, or *archegonia* (Fig. 209), organs which produce egg-cells, but in this moss antheridia and archegonia are not produced in the same "moss-flower." The plants therefore correspond to diœcious ones among flowering plants.

After the fertilization of the egg-cell, by the penetration of antherozoids to the bottom of the flask-shaped archegonium, the development of the egg-cell into *sporophyte* begins; the latter rises as a slender stalk, while the upper part of the archegonium is carried with it and persists for a time as the hood or *calyptra*.

CHAPTER XXII

TYPES OF CRYPTOGAMS; PTERIDOPHYTES

348. The Group Pteridophytes. — Under this head are classed the ferns, the scouring-rushes, and the club-mosses. They are the most highly organized of cryptogams, having true roots, and often well-developed stems and leaves.

THE STUDY OF A FERN[1]

349. Conditions of Growth. — If the specimens studied were collected by the class, the collectors should report exactly in regard to the soil and exposure in which the plants were found growing. Do any ferns occur in surroundings decidedly different from these? What kind of treatment do ferns need in house culture?

350. The Underground Portion. — Dig up the entire underground portion of a plant of ladyfern. Note the color, size, shape, and appendages of the rootstock. If any are at hand which were collected in their late winter or early spring condition, examine into the way in which the leafy parts of the coming season originate from the rootstock, and note their peculiar shape (Fig. 210, *A*). This kind of vernation (Sect. 136) is decidedly characteristic of ferns. Observe the number and distribution of the roots along the rootstock. Bring out all these points in a sketch.

[1] The outline here given applies exactly only to *Asplenium filix-fœmina*. Any species of *Asplenium* or of *Aspidium* is just as well adapted for study. *Cystopteris* is excellent, but the indusium is hard to find. *Polypodium vulgare* is a simple and generally accessible form, but has no indusium. *Pteris aquilina* is of world-wide distribution, but differs in habit from most of our ferns. The teacher who wishes to go into detail in regard to the gross anatomy or the histology of ferns as exemplified in *Pteris* will find a careful study of it in Huxley and Martin's *Biology*, or a fully illustrated account in Sedgwick and Wilson's *Biology*.

351. The Frond. — Fern leaves are technically known as *fronds*. Observe how these arise directly from the rootstock.

Make a somewhat reduced drawing of the entire frond, which consists of a slender axis, the *rhachis*, along which are distributed many leaflets or *pinnæ*, each composed of many *pinnules*. Draw the under side of one of the pinnæ, from near the middle of the frond, enlarged to two or three times its natural size, as seen through the magnifying glass. Note just how each pinnule is attached to its secondary rhachis.

Examine the under side of one of the pinnules (viewed as an opaque object without cover-glass) with the lowest power of the microscope, and note:

(*a*) The "fruit-dots" or *sori* (Fig. 210, *B*) (already seen with the magnifying glass, but now much more clearly shown).

(*b*) The membranous covering or *indusium* of each sorus (Fig. 210, *C*). Observe how this is attached to the veins of the pinnule. In such ferns as the common brake (*Pteris*) and the maidenhair (*Adiantum*) there is no separate indusium, but the *sporangia* are covered by the incurved edges of the fronds.

(*c*) The coiled spore-cases or sporangia, lying partly covered by the indusium. How do these sporangia discharge their spores?

Make a drawing, or several drawings, to bring out all these points.

Examine some of the sporangia, dry, with a power of about fifty or seventy-five diameters, and sketch. Scrape off a few sporangia, thus disengaging some spores, mount the latter in water, examine with a power of about 200 diameters, and draw.

352. Life History of the Fern. — When a fern-spore is sown on damp earth it gradually develops into a minute, flattish object, called a *prothallium* (Fig. 211). It is a rather tedious process to grow prothallia from spores, and the easiest way to get them for study is to look for them on the earth or on the damp outer surface of the flower-pots in which ferns are growing in a greenhouse. All stages of germination may readily be found in such localities.

Any prothallia thus obtained for study may be freed from particles of earth by being washed, while held in very small forceps, in a gentle stream of water from a wash-bottle. The student should then mount the prothallium, bottom up, in water in a shallow cell,

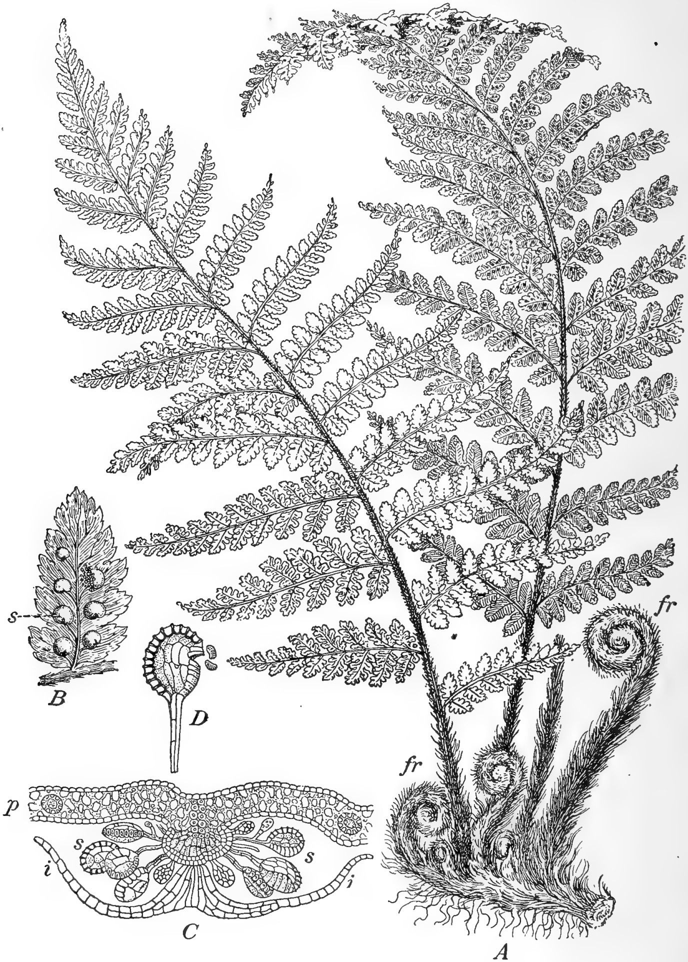


FIG. 210. — Spore-Plant of a Fern (*Aspidium Filix-mas*).

A, part of rootstock and fronds, not quite one-sixth natural size; *fr*, young fronds unrolling; *B*, under side of a pinnule, showing sori, *s*; *C*, section through a sorus at right angles to surface of leaf, showing indusium, *i*, and sporangia, *s*; *D*, a sporangium discharging spores. (*B* is not far from natural size. *C* and *D* are considerably magnified.)

cover with a large cover-glass, and examine with the lowest power of the microscope. Note:

(*a*) The abundant root-hairs, springing from the lower surface of the prothallium.

(*b*) The variable thickness of the prothallium, near the edge, consisting of only one layer of cells.

(*c*) (In some mature specimens) the young fern growing from the prothallium, as shown in Fig. 211, *B*.

The student can hardly make out for himself, without much expenditure of time, the structure of the *antheridia* and the *archegonia* (Fig. 211, *A*), by the coöperation of which fertilization takes place on much the same plan as that already described in the case of mosses. The fertilized egg-cell of the archegonium gives rise to the young fern, the *sporophyte* which grows at first at the expense of the parent prothallium but soon develops roots of its own and leads an independent existence.

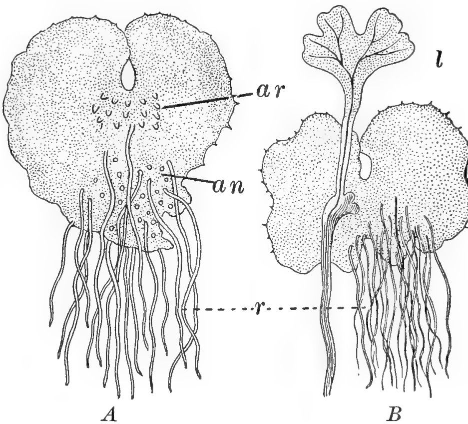


FIG. 211. — Two Prothallia of a Fern (*Aspidium*). *A*, under surface of a young prothallium; *ar*, archegonia; *an*, antheridia; *r*, rhizoids; *B*, an older prothallium with a young fern-plant growing from it; *l*, leaf of young fern. (Both × about 8.)

353. Nutrition. — The mature fern makes its living, as flowering plants do, by absorption of nutritive matter from the soil and from the air, and its abundant chlorophyll makes it easy for the plant to decompose the supplies of carbon dioxide which it takes in through its stomata.

FERNS

354. Structure, Form, and Habits of Ferns.—The structure of ferns is much more complex than that of any of the groups of cryptogamous plants discussed in the earlier portions of the present chapter. They are possessed of well-defined fibro-vascular bundles, they form a variety of parenchymatous cells, the leaves have a distinct epidermis and are provided with stomata.

Great differences in size, form, and habit of growth are found among the various genera of ferns. The tree ferns of South America and of many of the islands of the Pacific Ocean sometimes rise to a height of forty feet, while the most minute species of temperate and colder climates are not as large as the largest mosses. Some species climb freely, but most kinds are non-climbing plants of moderate size, with well-developed rootstocks, which are often, as in the case of the bracken-fern, or brake,[1] and in *Osmunda*, very large in proportion to the parts of the plant visible above ground.

355. Economic Value of Ferns.—Ferns of living species have little economic value, but are of great interest, even to non-botanical people, from the beauty of their foliage.

During that vast portion of early time known to geologists as the Carboniferous Age, the earth's surface in many parts must have been clothed with a growth of ferns more dense than is now anywhere found. These ferns, with other flowerless herbs and tree-like plants, produced the vegetable matter out of which all the principal coal beds of the earth have been formed.

[1] *Pteris aquilina.*

356. Reproduction in Ferns.—The reproduction of ferns is a more interesting illustration of alternation of generations than is afforded by mosses. The sexual plant, *gametophyte*, is the minute prothallium, and the non-sexual plant, *sporophyte*, which we commonly call the fern, is merely an outgrowth from the fertilized egg-cell, and physiologically no more important than the sporophyte of a moss, except that it supplies its own food instead of living parasitically. Like this sporophyte, the fern is an organism for the production of vegetative spores, from which new plants endowed with reproductive apparatus may grow.

THE STUDY OF A CLUB-MOSS (*LYCOPODIUM*)

357. Occurrence. — Several species of *Lycopodium* are common in rich woods in the northern and mountainous portions of the eastern United States. Any species may be studied.

358. Examination. — Note whether the plant is chiefly erect or prostrate and vine-like. Describe the mode of branching. Are the leaves arranged flat-wise or equally on all sides of the stem? Describe the leaves briefly. Are they all of one kind or do some portions of the plant evidently have smaller leaves?

Select fruiting specimens and determine the position of the sporangia. Is the leaf, near whose base each sporangium is situated, like the ordinary foliage leaves of the plant? Are the fruiting portions of the plant similar in general aspect or different from the rest of the plant and raised above it on stalks? Examine the spores. Are they all of one kind?

If *Selaginella* is used in place of *Lycopodium* or for comparison, two kinds of sporangia are to be sought, differing chiefly in shape. Describe each briefly. Compare the number of spores in each. The larger spores (*macrospores*) germinate and at length produce prothallia bearing archegonia, while the smaller produce prothallia bearing antheridia. The archegonia, after fertilization, develop each

an embryo. This grows, remaining for a time attached to the macrospore, and at length forms a new spore-plant.

THE STUDY OF A SCOURING-RUSH (*EQUISETUM*)

359. Occurrence. — The common horse-tail, *Equisetum arvense*, is widely distributed in the United States, east, west, north, and south. It is very often found on sand hills and along railroad embankments.

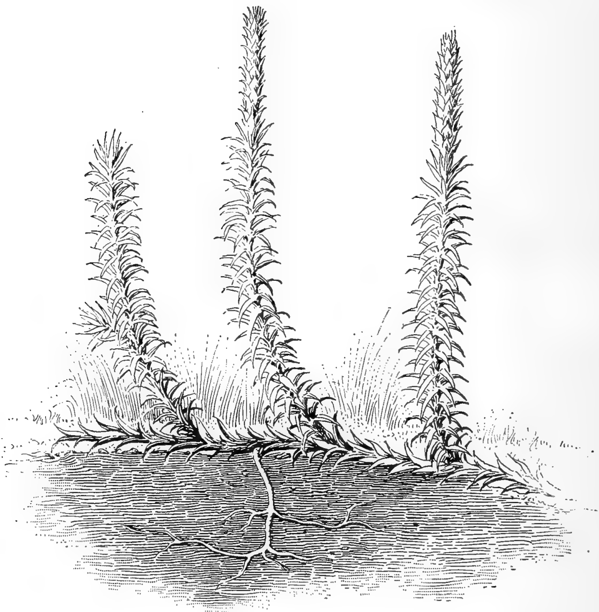


FIG. 212. — Plant of Lycopodium (*L. annotinum*).

The fruiting stems appear very early in the spring and are of short duration. The sterile vegetative growth follows, becoming well grown in June.

360. Examination of Rootstocks and Roots. — Examine the underground portions of the plant with reference to general size, position, color, shape, and position of notches. After studying the stems

above ground insert here any evident points of comparison. Do you find any special forms of stem development suited to a special purpose? Are there any organs in the nature of leaves?

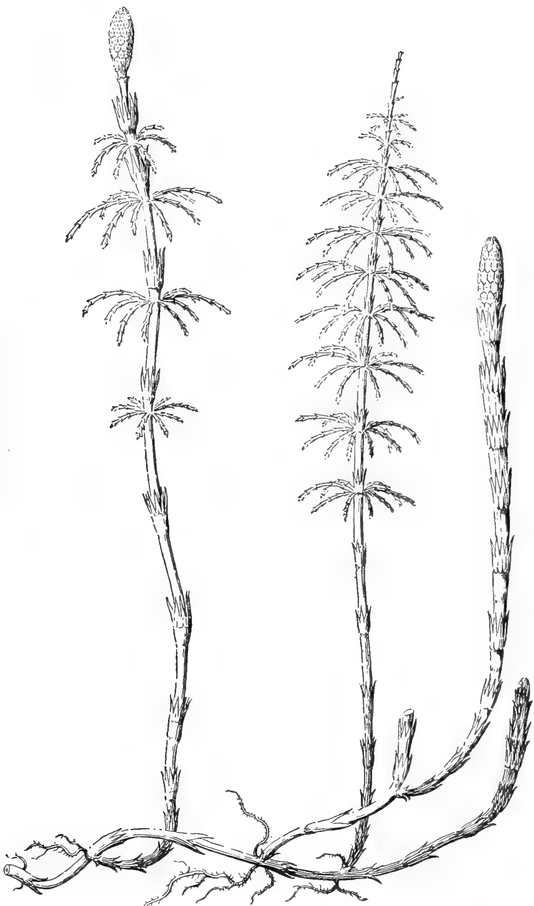


FIG. 213. — A Scouring-Rush (*Equisetum sylvaticum*). At the right is a colorless fertile stem, in the middle a green sterile one, and at the left a green fertile one.

361. Sterile Stems. — Examine the stems above ground with reference to their color and mode and degree of branching. What is the character of the leaves? Do the stems in any sense serve as leaves? Observe the nodes composing the stem and note the position of the leaves on the stems. Do they appear to be placed several at the same level (whorled)?

Examine with a magnifying glass the surface of the stem and note the number of ridges and grooves. Compare the number and position of the leaves with reference to these.

362. Mineral Matter in Stem. — Treat small pieces of the stem with strong nitric acid to remove all vegetable substance and note the mineral substance remaining. Treat in a similar way thin cross-sections and examine under the microscope. The substance is silica. It gives the plant its gritty feeling and its name and use as "scouring-rush." Of what use is it to the plant? Use of the same substance in outer rind of corn stem, bamboo stem, and straw of grains?

363. Microscopic Examination. — Make thin cross-sections of the stem and examine under the lowest power of the microscope. Make a diagrammatic sketch to indicate the central cavity, the number and position of the fibro-vascular bundles, the cavity or canal in each, the ring of tissue surrounding the ring of bundles, and the larger cavities or canals outside of this. Where is the chlorophyll located? Can stomata be found, and if so, what is their location and arrangement?

364. Fertile Stems. — Describe the fruiting stem with reference to general aspect, size, color, number, and length of internodes, position of spore-bearing portion, color of spores in mass. Note the shield-shaped bodies (transformed leaves or *sporophylls*) composing the cone-like "flower" and see whether any joints can be detected where they are attached. Examine the inner surface of the shields for sporangia and spores. Examine the sporangia under a low power of the microscope. Examine some spores under a higher power. Note the two bands, *elaters*, on each spore, crossing each other and attached only at the point of crossing, forming four loose appendages. Watch these while some one moistens them by gently breathing upon them as they lie uncovered on the slide under the microscope

and note the effect. Also note the effect of drying. How does this affect the spores? Use of the bands?

365. Germination of Spores. — The spores germinate while fresh and form prothallia corresponding to those of ferns, but generally diœcious. The prothallium which bears the antheridia remains comparatively small, and the antheridia are somewhat sunken. The others grow much larger and branch profusely. The terminal portion becomes erect and ruffled. Near this part the archegonia are formed, quite similar to those of ferns. The embryo plant developing from the germ-cell has its first leaves in a whorl. This at length grows into a spore-plant like that shown in Fig. 213.

About twenty-five species of *Equisetum* are known. Several may be looked for in any locality and may well be compared with the one described above, in regard to form, mode of branching, and mode of fruiting.

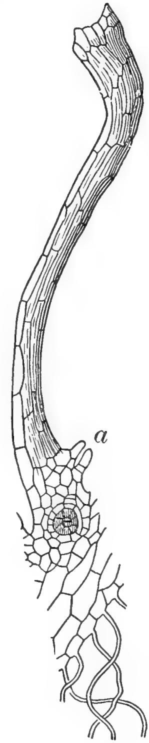


FIG. 214. — Part of a Lobe of the Mature Female Prothallium of *Equisetum*. (× about 50.)

a, mouth of a fertilized archegonium.

366. Fern-Plants (Pteridophytes). — The *Pteridophytes* (literally fern-plants) include in their general category not only ferns as commonly recognized, but several other small groups which are very interesting on account of their diversity. All cryptogams higher than mosses belong in this group. In moss plants the individuals growing from spores and bearing antheridia and archegonia, the gametophytes, are full-grown leafy plants, and the spore-bearing plant, or sporophyte, is merely a stalk bearing a sporangium. In all the fern-plants the reverse is true. The individuals growing from spores and bearing antheridia and archegonia are of

minor vegetative development (*prothallia*), while the spore-bearing plant is a leafy plant, even a tree in some ferns.

The ferns in the strictest sense have sporangia derived from the epidermis (transformed hairs), while a few plants closely resembling them in general aspect (*Botrychium*, etc.) have sporangia formed in the tissue of the leaf.

In the next subdivision, the water-ferns (Fig. 215), there is little resemblance to the common ferns. The sporangia are in special receptacles at the basal portion of the plant. The spores are of two kinds, *diœcious*, one on germination, producing antheridia, the other archegonia. This group includes two rooting forms, *Marsilea* (with leaves resembling a four-leaved clover) and *Pilularia*, bearing simple linear leaves, and two floating forms, *Salvinia* (Fig. 215) and *Azolla*.

The remaining groups of fern-plants are the horse-tails and the club-mosses. The horse-tails have only one kind of spore and are peculiar chiefly in their vegetative aspect (Fig. 213), while the spore-bearing leaves, or sporophylls, are arranged in the form of a cone, as already shown.

The club-mosses include some plants which, as their name implies, have a superficial resemblance to a large moss, with the addition of a club-shaped stalked fruiting spike. These are the so-called "ground pines" and the running ground "evergreens" used for Christmas festoons in New England. Technically the group is distinguished by the possession of firm-walled sporangia formed singly near the bases of the leaves. The ordinary club-mosses already referred to have but one kind of spore, while plants called *Selaginella* and *Isoetes* have two kinds of spores, in this respect resembling *Marsilea*. In many

species of *Selaginella* the leaves are arranged flat-wise on the stem, so that considered physiologically the branching stem and its leaves together serve as a foliage leaf. In one of the commonest American forms, however, the stem is more nearly erect, and the leaves are all alike and four-ranked.

Isoetes (quill-wort) grows attached to the soil in shallow water at the bottoms of ponds. It has the aspect of short grass growing in bunches. The large sporangia are at the broad bases of the leaves.

367. High Organization of Pteridophytes. — The student may have noticed that in the scouring-rush and the club-moss studied there are groups of leaves greatly modified for the purpose of bearing the sporangia. These groups are more nearly equivalent to flowers than anything found in the lower spore-plants, and the fern-plants which show such structures deserve to be ranked just below seed-plants in any natural system of classification.

The variety of tissues which occur in pteridophytes is frequently nearly as great as is found in ordinary seed-plants, and the fibro-vascular system is even better developed in many ferns than in some seed-plants.

Starch-making is carried on by aid of abundant chlorophyll bodies contained in parenchyma-cells to which carbonic acid gas is admitted by stomata. In many cases large amounts of reserve food are stored in extensive root-stocks, so that the spring growth of leaves and stems is extremely rapid.

CHAPTER XXIII

THE EVOLUTIONARY HISTORY OF PLANTS

368. The Earliest Plant Life.—What sort of plants first appeared on the earth has never been positively ascertained. The oldest known rocks contain carbon (in the form of black lead or graphite) which may represent the remnants of plants charred at so high a temperature and under so great pressure as to destroy all traces of plant structure. Some objects supposed by many to be the remains of large algæ have been found in rocks that date back to a very early period in the life history of the earth, before there were any backboned animals, unless possibly some fishes. Judging from the way in which the various groups of plants have made their appearance from the time when we can begin clearly to trace their introduction upon the earth, it is probable that some of the simplest and lowest forms of thallophytes were the first to appear. Decaying animal or vegetable matter must have been less abundant than is now the case, so that a plant that could make part or all of its food from raw materials would have had a better chance than a saprophyte that could not. Water-plants are usually simpler than land-plants, so it is highly probable that some kind of one-celled aquatic alga was the first plant.

369. Fossil Plants.—*Fossils* are the remains or traces of animals or plants preserved in the earth by natural processes. Fossil plants, or parts of plants, are very

common; the impressions of fern-leaves in bituminous coal and pieces of wood turned into a flint-like substance are two of the best known examples.

The only way in which we can get knowledge about the animals and plants that inhabited the earth's surface before men did is by studying such rocks as contain the remains of living things. In this way a great deal of information has been gained about early forms of animal life and a less amount about early plant life, — less because as a general thing plants have no parts that would be as likely to be preserved in the rocks as are the bones and teeth of the higher animals and the shells of many lower ones.

370. The Law of Biogenesis. — An extremely important principle established by the study of the development of animals and plants from the egg or the seed, respectively, to maturity is this: *The development of every individual is a brief repetition of the development of its tribe.* The principle just stated is known as the law of biogenesis. As eggs develop during the process of incubation, the young animals within for a considerable time remain much alike, and it is only at a comparatively late stage that the wing of the bird shows any decided difference from the fore-leg of the alligator or the turtle. Zoölogists in general are agreed that this likeness in the early stages of the life history of such different animals proves beyond reasonable doubt that they all have a common origin, that is, are descended from the same kind of ancestral animal.

Among plants the liverworts and ferns supply an excellent illustration of the same principle. In both of the groups the fertilized egg-cells, as the student may have learned

by his own observations, are much alike. As the egg-cell grows and develops, the sporophyte of a liverwort, which proceeds from the egg-cell, is extraordinarily unlike the "fern" or asexual generation (gametophyte) among Filices. Now this progressive unlikeness between liverworts and ferns, as they develop from the fertilized egg-cell, points to the conclusion that both groups of plants have a common origin or that the more highly organized ferns are direct descendants of the less highly organized liverworts.

371. Plants form an Ascending Series. — All modern systems of classification group plants in such a way as to show a succession of steps, often irregular and broken, seldom leading straight upward, from very simple forms to highly complex ones. The humblest thallophytes are merely single cells, usually of microscopic size. Class after class shows an increase in complexity of structure and of function until the most perfectly organized plants are met with among the dicotyledonous angiosperms. During the latter half of the present century it first became evident to botanists that among plants *deep-seated resemblances imply actual relationship, the plants which resemble each other most are most closely akin by descent, and (if it were not for the fact that countless forms of plant life have wholly disappeared) the whole vegetable kingdom might have the relationships of its members worked out by a sufficiently careful study of the life histories of individual plants and the likeness and differences of the several groups which make up the system of classification.*[1]

[1] See Campbell's *Evolution of Plants* and Warming's *Systematic Botany*, Preface and throughout the work. In the little flora of the present book, the families are arranged in the order which, according to the best recent German authorities, most nearly represents their relationships.

372. Development of the Plant from the Spore in Green Algæ, Liverworts, and Mosses. — The course which the forms of plant life have followed in their successive appearance on the earth may be traced by the application of the law above named. Such algæ as the pond-scums produce spores which give rise directly to plants like the parent.

In many liverworts the spore by its germination produces a thallus which at length bears antheridia and archegonia. The fertilized archegonium develops into a sporophyte which remains attached to the thallus, although it is really a new organism. Liverworts, then, show an alternation of generations, one a sexual thallus, the gametophyte, the next a much smaller, non-sexual sporophyte, and so on.

A moss-spore in germination produces a thread-like protonema which appears very similar to green algæ of the pond-scum sort. This at length develops into a plant with stem and leaves, the sexual generation of the moss. The fertilized archegonium matures into a sporophyte which is the alternate, non-sexual generation. This is attached to the moss-plant, or gametophyte, but is an important new organism. In the moss, as in the liverwort, the sexual generation is the larger and the more complex ; the non-sexual generation being smaller and wholly dependent for its food supply on the other generation, to which it is attached.

373. Development of the Plant from the Spore in Pteridophytes. — In the pteridophytes there is an alternation of generations, but here the proportions are reversed, the prothallium, or sexual generation, or gametophyte, being short-lived and small (sometimes microscopic), and the

non-sexual generation, the sporophyte, often being of large size. The ferns (non-sexual generation), for instance, are perennial plants, some of them tree-like.

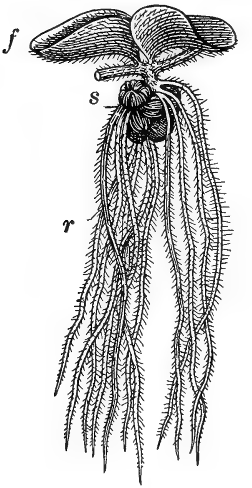


FIG. 215.—A Water-Fern (*Salvinia*).

Some pteridophytes, as the *Salvinia*, a small floating aquatic plant, sometimes known as a water-fern (Fig. 215), produce two kinds of spores, the large ones known as *macrospores*, and the small ones known as *microspores* (Fig. 216). Both kinds produce microscopic prothallia, those of the former bearing only archegonia, those of the latter only antheridia. From the prothallia of the macrospores a plant (non-sexual generation) of considerable complexity of structure is formed.

374. Parts of the Flower which correspond to Spores. — In seed-plants the spore-formation of cryptogams is represented, though in a way not at all evident without careful explanation. The pistil is the macrospore-producing leaf or *macrosporophyll*, and the stamen is the microspore-producing leaf or *microsporophyll*. Pines and other gymnosperms produce a large cell (the embryo sac) in the ovule (Fig. 217), which corresponds to the macrospore, and a pollen grain which represents the microspore. In its

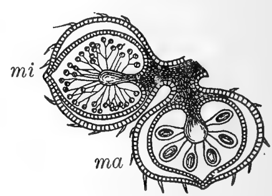


FIG. 216.—Two Indusia of *Salvinia*. *mi*, microspores; *ma*, macrospores.

development the macrospore produces an endosperm which is really a small cellular prothallium, concealed in the ovule. The microspore contains vestiges of a minute prothallium.

In the angiosperms the macrospore and its prothallium are still less developed, and the microspore, or pollen grain, has lost all traces of a prothallium and is merely an antheridium which contains two generative cells.[1] These are most easily seen in the pollen grain, but sometimes they are plainly visible in the pollen tube (Fig. 164).

Phanerogams are distinguished from all other plants by their power of producing seeds, or enclosed macrosporangia, with embryos.

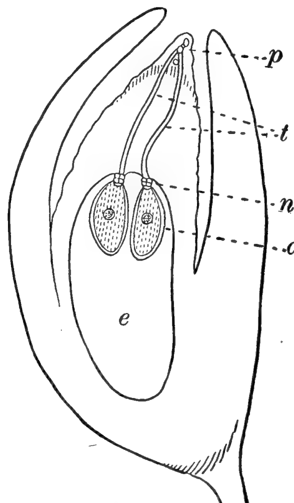


FIG. 217.—Longitudinal Section through Fertilized Ovule of a Spruce.

p, pollen grains; *t*, pollen tubes; *n*, neck of the archegonium; *a*, body of archegonium with nucleus; *e*, embryo sac filled with endosperm.

375. The Law of Biogenesis and the Relationships of the Great Groups of Plants.—On summing up Sects. 372–374 it is evident that the sexual generation in general occupies a less and less important share in the life of the plant as one goes higher in the scale of plant life.[2] In the case of the rockweed, for instance, the sexual generation is the plant. Among mosses and liverworts the sexual

[1] Sometimes only one generative cell escapes from the pollen grain into the pollen tube, and there it divides into two cells.

[2] A good many plants of low organization, however, are not known to pass through any sexual stage.

generation is still very prominent in the life of the plant. Ordinary ferns show us the sexual generation existing only as a tiny independent organism, living on food materials which it derives from the earth and air. In the *Salvinia* it is reduced to microscopic size and is wholly dependent on the parent-plant for support. Among seed-plants the sexual generation is so short-lived, so microscopic, and so largely enclosed by the tissues of the flower that it is comparatively hard to demonstrate that it exists.

The fact that the life history of so many of the classes of plants embraces a sexual stage, in which an egg-cell is fertilized by some sort of specialized cell produced wholly for use in fertilization, tends strongly to show the common origin of the plants of all such classes. We have reason to believe, from the evidence afforded by fossils, that plants which have only a sexual generation are among the oldest on the earth. It is therefore likely that those which spend the least portion of their entire life in the sexual condition were among the latest of plants to appear. Then, too, those which have the least developed sexual generation are among the latest of plants. Judged by these tests the angiosperms must be the most recently developed of all plants.

If one were to attempt to arrange all the classes of existing plants in a sort of branching series to show the way in which the higher plants have actually descended from the lower, he would probably put some one of the green algæ at the bottom and the angiosperms at the top of the series.

376. The Oldest Angiosperms. — It is impossible to give any of the reasons for the statements of this section

without making an unduly long chapter. Briefly, it may be stated that the monocotyledons are the simplest and probably the oldest angiosperms; the dicotyledons are higher in organization and came later. The descent and various relationships of the families of dicotyledons can be discovered by the study of the flower, fruit, and seed better than by the examination of the vegetative organs.

The entire pedigree of the several families cannot be represented by arranging the names of the families in a straight line. It is, however, in a general way, as indicated by the succession of families in the Flora which accompanies this book, the Willow Family being perhaps the oldest (of the more familiar ones) and the Composite Family the youngest.

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